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Multimedia Electronic Mail: Standards
and
Performance Simulation
by

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This thesis surveys the current multimedia electronic mail (e-mail) related standards. The increasing demands for interoperability pushed the international standardization organizations to develop standards for e-mail. The multimedia e-mail related standards include X.400 and ODA. ODA supports formatted text, raster graphics, and geometric graphics. The future standard will be able to support high bandwidth uses such as high-resolution color still-image, full-motion video, voice, and audio. The future components of multimedia e-mail will include TIFF for raster graphics, CGM for geometric graphics, JPEG for high resolution color still-image, and MPEG for full-motion video. These multimedia data require vast amounts of storage, processing time, and transmission bandwidth. The standardization efforts can be viewed as selecting the best combination of these three factors, interoperability, and timing consideration. According to this view, the standard for each component is reviewed with frame of background, coding, compression, and current status. With the information from the survey study, a simulation study is conducted to investigate the performance of LAN where multimedia data are transmitted. The simulation results show that the high resolution image browsing activity in a LAN will burden the low speed LANs. The adoption of compression chips or high speed LANs such as FDDI will make such high bandwidth activities feasible.

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Multimedia Electronic Mail: Standards and Performance Simulation

by

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Captain, Republic of Korea Army
B.S., Korea Military Academy, 1987

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of the requirements for the degree of

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ABSTRACT

This thesis surveys the current multimedia electronic mail (e-mail) related standards. The increasing demands for interoperability pushed the international standardization organizations to develop standards for e-mail. The multimedia e-mail related standards include X.400 and ODA. ODA supports formatted text, raster graphics, and geometric graphics. The future standards will be able to support high bandwidth uses such as high-resolution color still-image, full-motion video, voice, and audio. The future components of multimedia e-mail include TIFF for raster graphics, CGM for geometric graphics, JPEG for high resolution color still-image, and MPEG for full-motion video. These multimedia data require vast amounts of storage, processing time, and transmission bandwidth. The standardization efforts can be viewed as selecting the best combination of these three factors, interoperability, and timing consideration. According to this view, the standard for each component is reviewed with frame of background, coding, compression, and current status. With the information from the survey study, a simulation study is conducted to investigate the performance of LAN where multimedia data are transmitted. The simulation results show that the high resolution image browsing activity in a LAN will burden the low speed LANs. The adoption of compression chips or high speed LANs such as FDDI will make such high bandwidth activities feasible.

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I. INTRODUCTION

A. BACKGROUND

The technologies in telecommunication changed the concepts about geographical distances and boundaries of the world. The innovative new technologies are implemented and being offered to the public in breathtaking speed. One of the new technologies is the multimedia electronic mail (e-mail). As in the telephone network, the increase of value which the user gets from the e-mail system is proportional to the increasing number of subscribers. If one subscriber cannot communicate with other subscribers, the value of the network will decrease. The interconnection and interoperation with others motivated the standardization efforts, both nationally and internationally, backed by governmental organizations and private industries.

Multimedia e-mail is an application of multimedia computing and telecommunications. It combines various media (e.g., text, raster graphics, vector graphics, still-images, full-motion video, spreadsheets, animations, voice, and audio) into electronic document form to transmit to remote recipients. The potential usefulness of multimedia e-mail is enormous. It will significantly enhance the individual's communication skill and efficiency by selecting the most suitable form of media for communicating ideas.

The need for standards on multimedia e-mail system is widely recognized. For example, the U.S. government adopted the standards for multimedia e-mail as a part of Government Open System Interconnection Protocol (GOSIP). The two major standards

-- X.400 [Message Handling System (MHS)] and Office Document Architecture (ODA) -- are a part of GOSIP [Ref. 2]. Figure 1 illustrates the position of MHS and ODA in GOSIP environment.

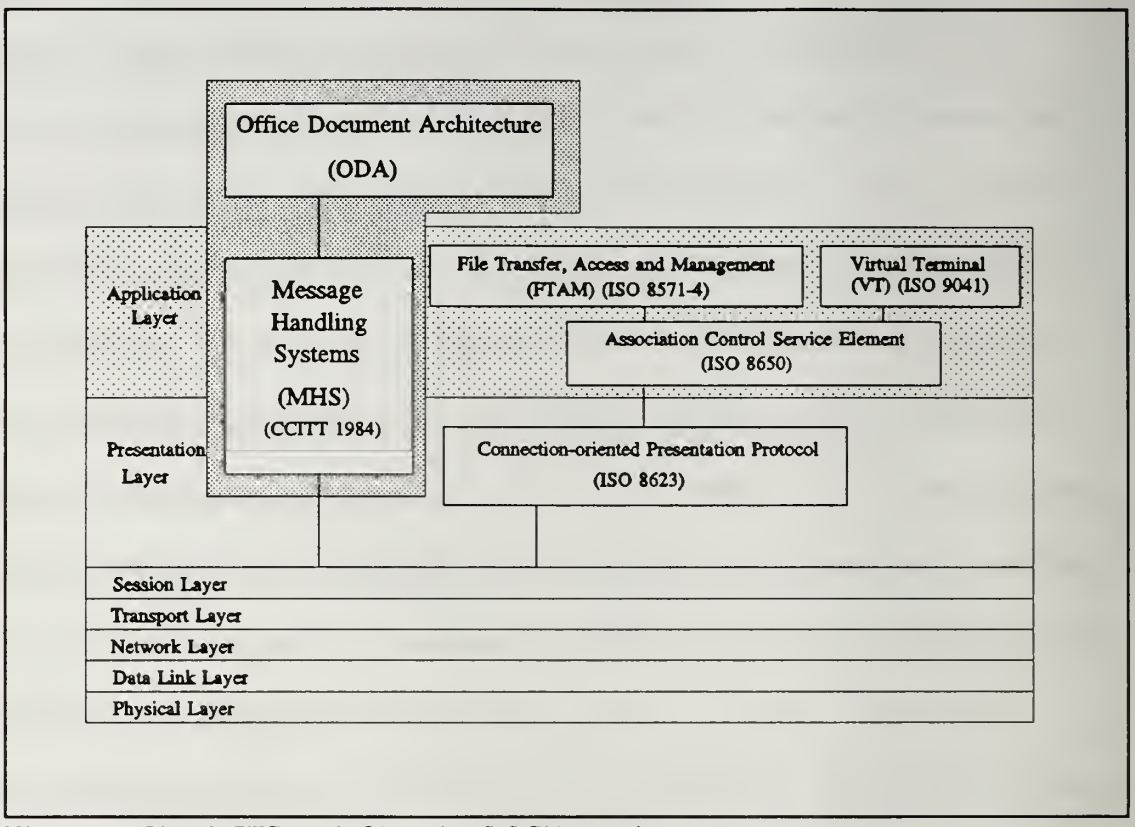

Figure 1. The MHS and ODA in GOSIP environment

B. OBJECTIVES

There are many studies on multimedia e-mail systems, but some are too broad to show detailed pictures and some are too narrow to show the whole scene. The main intention of this thesis is to provide the reader with a clear, current, and in-depth view of multimedia e-mail system and their standardization environment by surveying its standards organizations and related standards. In addition to the survey part, a basic

simulation analysis is done to investigate the performance of a Local Area Network (LAN) where multimedia data are transmitted.

C. LITERATURE REVIEW AND METHODOLOGY

One of the difficulties inherent in studying multimedia e-mail is the dynamic standards environment in which it operates. The development life cycle of current technologies is getting short. These fast and continuously changing technologies and standards required the author to focus on the most up-to-date information at the time of writing. In the survey study, most of the information came from current technical journals, and computer and communication related magazines. General multimedia applications, multimedia e-mail, and MHS related studies can be found in [Ref. 1 - 17]. General ODA information came from [Ref. 18 - 24], and ODA components standards information came from [Ref. 25 - 80].

In the simulation part, the subset of multimedia LAN is modeled and simulated using both LAN-oriented simulation tool and a general simulation language. Also, related studies [Ref. 81 - 89] are investigated to support the results.

D. ORGANIZATION OF STUDY

The main body of this thesis is composed of four chapters: multimedia e-mail and its related standards, components standards, modeling of a multimedia LAN, and analysis of the simulation results.

Chapter II reviews the major international organizations for standardization which include International Organization for Standardization (ISO) and International Telegraph

and Telephone Consultative Committee (CCITT). These organizations' structure and the procedure of standardization are briefly reviewed. The multimedia e-mail related standards are described with an emphasis on Message Handling Systems (MHS) and ODA.

Chapter III surveys the content structure of ODA which defines the format of the message components of multimedia e-mail. Included are current components (e.g., text, raster graphics, and geometric graphics) and future components (still-image and full-motion video).

Chapter IV models a subset of multimedia LAN based on information from previous chapters. The model describes an image browsing activity in a token ring network which has transmission speeds of 4, 16, or 100 Mbps. The model takes into account the effect of multimedia data, e.g., vast amount of transmission needs, and the application of compression technologies.

Chapter V verifies, presents, and analyzes the simulation results. Two properties of LAN performance are collected and presented. The results from different simulation tools and language are compared to verify the model.

Chapter VI contains a summary and conclusions.

II. MULTIMEDIA ELECTRONIC MAIL AND ITS RELATED STANDARDS

A. OVERVIEW

Electronic mail (e-mail) is now widely recognized as providing an effective means of asynchronous communication between computer users, bridging the gap between the traditional paper and telephone-based forms of communication. But, the current e-mail supports the message which only contains text form of information. Multimedia mail is an extension of the text-based e-mail model to incorporate formatted text, voice, stereo audio, raster and vector graphics, animations, and full-motion video. The power of multimedia mail lies in its ability to improve communications and promote group collaboration by conveying information in one or more media to one or more users, thus allowing the communication of ideas and concepts in the most suitable medium or combination of media.

Compared with text-only e-mail, multimedia mail needs more sophisticated technologies and standards for creating, editing, transferring, and viewing messages. The standards are critical for multimedia mail. Without a standard representation format, users can never be certain that any multimedia messages they send will actually be readable by its recipients [Ref. 10]. Few users will spend time to create multimedia documents if they do not expect them to be readable.

This chapter describes the role international organizations play in the multimedia mail area and overviews their major outcomes: Office Document Architecture (ODA) and X.400-series recommendations. ODA defines the architecture of documents to be

exchanged as contents of multimedia mail, and X.400 represents protocols for e-mail interchange. This paper will focus on ODA and its components rather than on X.400 standards since the former has more direct impacts on network traffic than the latter. Chapter III will provide a detailed survey of ODA components such as TIFF (Tagged Interchange File Format), CGM (Computer Graphics Metafile), JPEG (Joint Photographic Expert Group), and MPEG (Moving Picture Expert Group).

B. INTERNATIONAL ORGANIZATIONS FOR MULTIMEDIA MAIL STANDARDIZATION

1. International Organization for Standardization (ISO)

The International Organization for Standardization (ISO) is a voluntary, non-treaty agency of the United Nations. The scope of studies in ISO is very broad and includes such fields as agriculture, nuclear systems, fabrics, documents used in commerce, library science, computer systems, and computer communication [Ref. 1]. The majority of the work in ISO is handled in the technical committees (TC) and their subunits named subcommittees (SC) and working groups (WG). The development of an ISO standard is a time-consuming process because many countries and steps are involved. A brief summary of the process is provided here [Ref. 17]:

- A new proposal is assigned to a technical committee (TC) which produces a document containing the technical features of the specification. This document is called a working draft (WD).
- As a result of technical review and editorial refinements on the WD, a modified document is prepared. At this time, the document becomes a draft proposal (DP).
- The TC and the Central Secretariat review the proposal and issue it as a draft international standard (DIS). At this juncture, the major comments and

corrections have been taken into account, and the document is circulated for a member body vote.

- The DIS is reviewed and voted upon by members, and eventually published as an international standard (IS). At this point, the document is considered to be technically and editorially correct. It is then published in French, English, and Russian.

Technical Committee 97 (TC97) deals with information technology. Its subcommittee 18 (SC18) is developing standards for e-mail system interconnection, or text preparation and interchange. Working Group 3 (WG3) of SC18 is developing standards for a message body format and is further along in this area than most other standards organizations. WG 4 is developing standards for a message heading format and for massaging-related protocols [Ref. 8].

2. International Telegraph and Telephone Consultative Committee (CCITT)

The International Telegraph and Telephone Consultative Committee is a member of the International Telecommunications Union (ITU), a treaty organization formed in 1965. CCITT sponsors a number of recommendations dealing primarily with data communications networks, telephone switches, and digital systems and terminals. Like other standards organizations, CCITT is also criticized for its lengthy process in making standards available to the public. CCITT's usual process of standardization is summarized as follows:

- Standards group sets up a broad framework from which the standard could be developed.
- The standard is made as detailed as possible, given a time constraint.
- The standard might be issued with certain pieces unfinished (with the notation "Further Study").

- The standard is then published.
- As it is used, the "gaps" are filled in, deficiencies are noted, and modifications are made in the light of practical operating experience.
- Whole process takes four years. At the end of each process, CCITT publishes updated series of recommendations. Those books are identified by color of covers. The 1960 books were red; 1964, blue; 1968, white; 1972, green; 1976, orange; 1980, yellow; 1984, once again red; 1988, blue [Ref. 16].

The CCITT Study Group VII is responsible for the X-series recommendations. CCITT's Study Group VII (SG VII) began work on e-mail system interconnection officially in March 1981. Its comprehensive work should culminate in specifications for message handling services: namely, the submission, relaying, and delivery protocols; the structure of user names; the format of the heading and body of messages; and methods of inter-working with Teletex terminals [Ref. 8]. The X-series recommendations are categorized according to the functions and services they provide and are then further classified into the specific recommendations.

C. X.400: MESSAGE HANDLING SYSTEMS (MHS)

1. Overview

CCITT published the initial Message Handling Systems (MHS) standards in 1984, and improved and extended the original standards in 1988. They consist of nine recommendations from X.400 to X.420.

The MHS standards define two types of services to support e-mail. First, the Message Transfer Service (MTS) is responsible for application-independent delivery. Its operations are centered on the envelop of the message. Second, the InterPersonal Messaging (IPM) Service supports communications with existing telex and telematic

services and defines specific user interfaces with MHS. It is responsible for the contents within the envelope. Figure 2 shows the correspondence between an MHS message and a conventional mail.

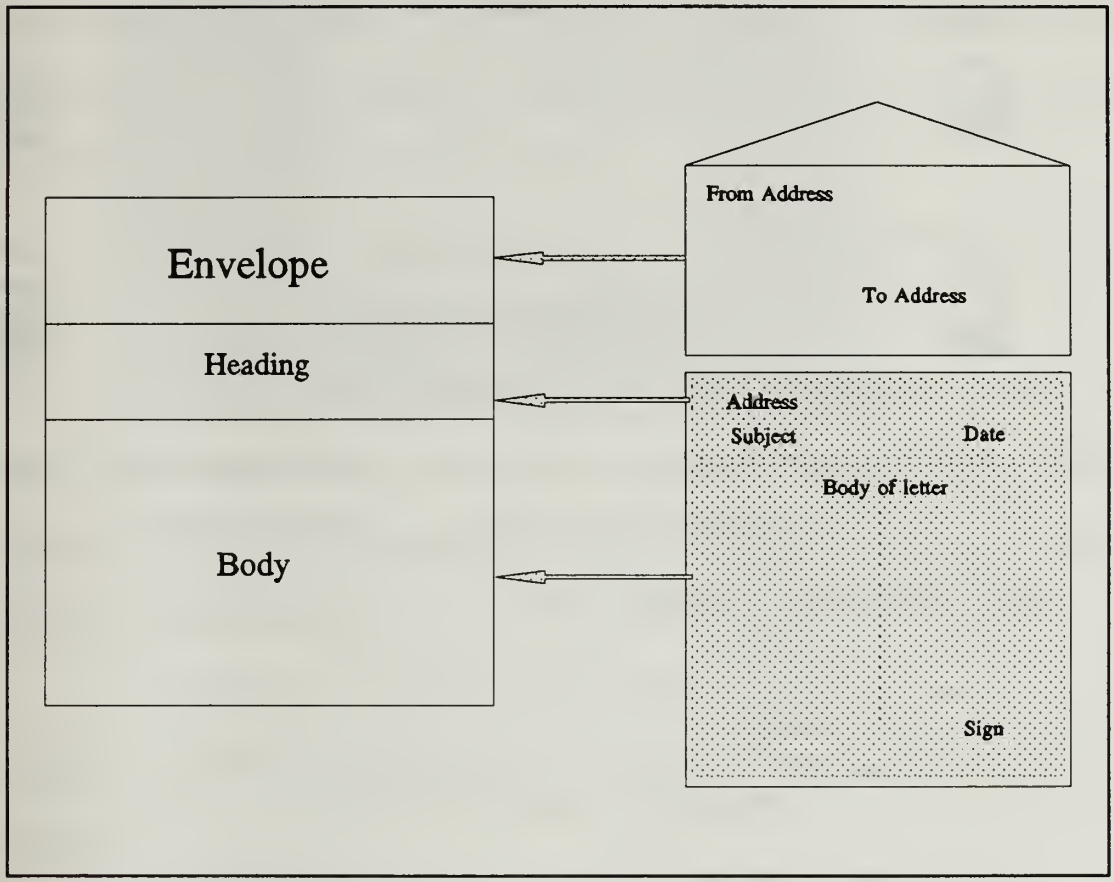

Figure 2. A MHS message and a letter

2. The structure of MHS

MHS consists of five elements: User Agent (UA), Message Transfer Agent (MTA), Message store (MS), and Access Unit (AU). Figure 3 shows the relationship among these elements.

The User Agent (UA) is responsible for directly interfacing with the end user. It prepares, submits, and receives messages for the user. The services UA provides

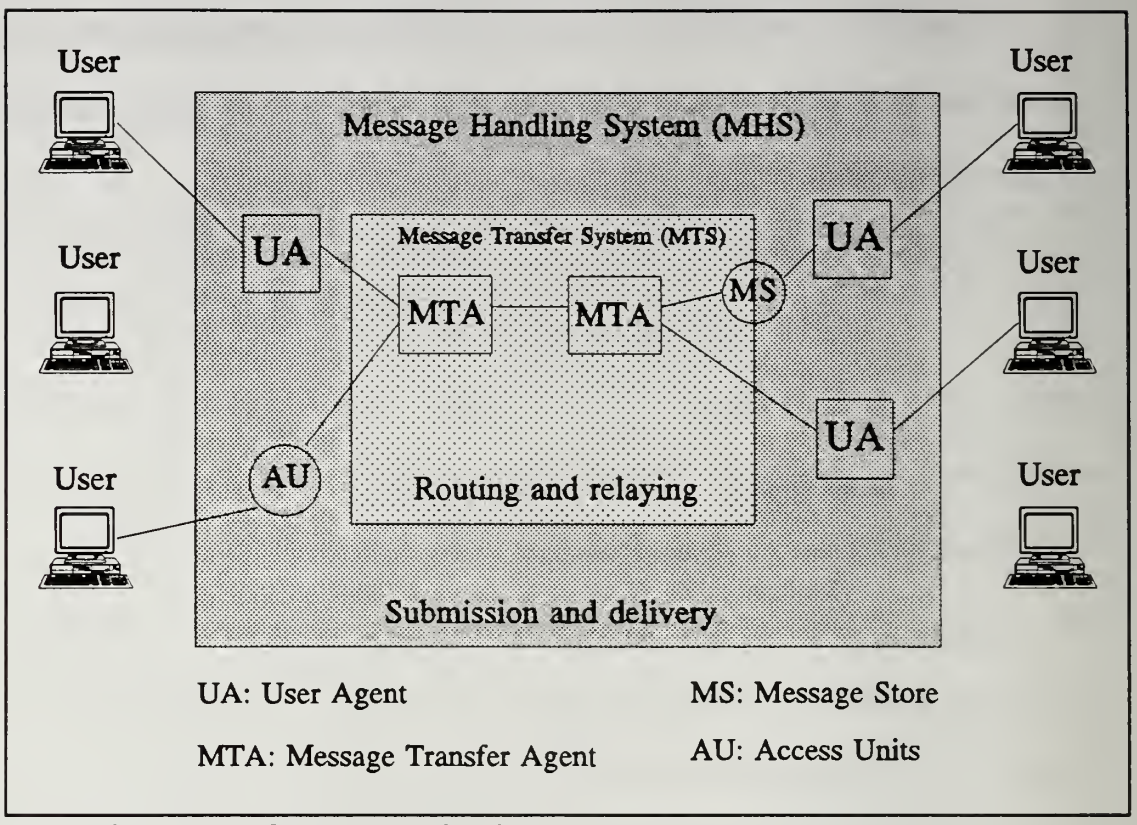

Figure 3. The MHS model [Ref. 16]

are summarized as follows:

- Text editing and presentation services for end users
- User-friendly interaction
- Security, priority provision, delivery notification, and distribution of subsets of documents.

UAs are grouped into classes by MHS based on the types of messages they can process. These UAs are then called cooperating UAs.

The Message Transfer Agent (MTA) provides the routing and relaying of the message. This function is responsible for the store-and-forward path, channel security,

and the actual message routing through the communications media. A collection of MTAs is called the Message Transfer System (MTS).

The Message Store (MS) provides for the storage of messages and support their submission and retrieval. The MS complements the UA for machines such as personal computers and terminals that are not continuously available. The job of MS is to provide storage that is continuously available.

The Access Unit (AU) supports connections to other types of communications systems, such as telematic services, postal services, etc.

The MHS conveys three kinds of information: message, probes, and reports. The message consists of the envelope which carries the information needed to transfer the message and the content which is the information the originating UA wishes delivered to one or more UAs.

The probe is an information object that only contains an envelope. It is delivered to the MTAs serving the end users. It is used to determine if the message can be delivered.

The report is a status indicator. It is used by the MTS to relate the progress or outcome of a message's or probe's transmission to one or more potential users.

D. OFFICE DOCUMENT ARCHITECTURE (ODA)

1. Overview

ODA is an international standard to facilitate the exchange of multimedia documents, as defined by ISO 8613 [Information Processing - Text and Office System-Office Document Architecture] developed by ISO TC97/SC18. The development started

in 1982 and was finally standardized after seven-year efforts in 1988. But the process is still going on to allow us to add more components to a document. Current standards only allow formatted text, raster graphics, and geometric[1] graphics, but the future standards will include video, voice, audio, animation, etc.

Currently, American Standard Code for Information Interchange (ASCII) is the only vendor-independent and most widely used format for text data exchange, but it is useless for exchanging information regarding the layout and the character attributes such as bolding, underlining, and italicizing. On the other hand, ODA supports the interchange of documents which contain picture and tabular materials. ODA will promote the communication of the intentions of the author with respect to content and appearance in different presentation media by means of a common set of rules. ODA is a complex standard because almost every program for processing text, graphics, and images has its own format for describing and storing information.

The ODA standard is composed of seven parts as seen in Figure 4. Part I overviews the overall framework of ODA and the remaining parts describe details of the following issues:

- Document profile
- Document structure
- Interchange format
- Document processing
- Content format.

---

[1] Vector graphics is another name for geometric graphics.

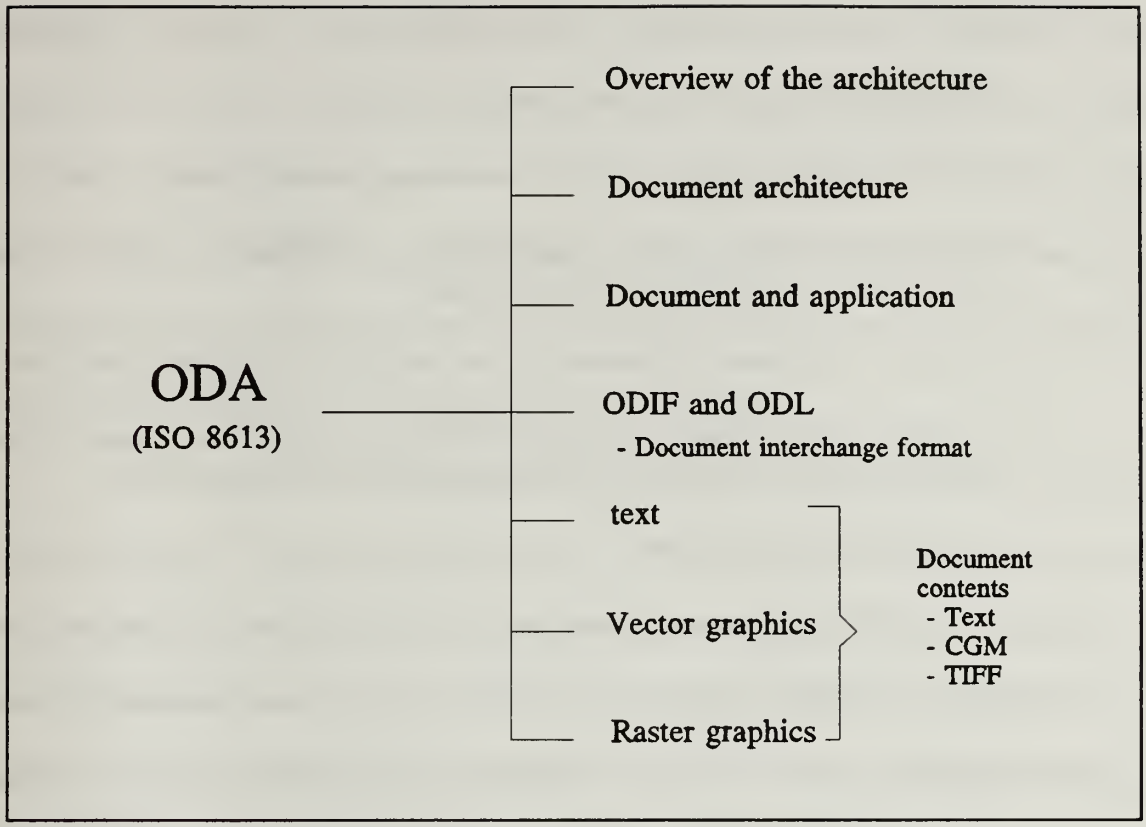

Figure 4. The composition of ODA

Each of these issues will be briefly discussed in this section.

2. Document profile

The document profile is sent as a header at the start of data stream. The profile can be sent separately from the document itself to help the recipient decide whether he can process the document (recipient with text-only screen may not view the graphics portion of the document). If the receiving system is not able to process the profile, the originator need not bother sending the attached document.

The document profile consists of a set of attributes at the higher level in the document structure. The first part identifies the title, author and date the document was created. The second part includes a set of attributes applied to the document as a whole

[Ref. 22]. The role of document profile in a document is to give an overall definition of the document characteristics, specifying the following:

- Its title, version number, subject, summary, table of contents, etc.
- Its history: author's name, day of creation, modification, period of validity, organization responsibility for the document.
- The form of document: formatted, processable, or formatted processable.
- Its internal characteristics: nature of the objects, a list of fonts, character sets and character attributes used within the entire document [Ref. 19, 22].

3. Document structure

The document structure answers the question of how ODA sees and describes a document. In ODA, a document is *an amount of structured information that can be interchanged as a unit*. The overall document architecture is the collection of rules for defining the structure and representation of document [Ref. 22].

ODA structure consists of logical structure and layout structure. The logical structure associates the content of the document with a hierarchy of logical objects such as summaries, titles, sections, paragraphs, figures, and tables. The layout structure associates the same content with a hierarchy of layout objects such as page sets, pages, frames, columns, blocks, etc. This separation provides more than two means of interchange. The layout view is useful for interchange of information regarding a document's appearance; the logical view is useful for exchanging content that may be revised.

The logical structure divides the contents of a document as a function of the semantic description desired by the author. In this way, the notions of chapter,

paragraph, summary, note, indent, table of content, etc, may appear [Ref. 19]. There are three types of logical objects ODA allows: basic, composite, and root (document). Basic objects have no subordinates and they include the objects such as date, subject, paragraph, graphic, image, and signature. The composites have subordinates of basic objects and they include header, summary, figure, etc. The root is the top level and it has subordinates of composite objects.

To present a document on paper or on a screen, the logical structure is no longer necessary. The document must then be divided into physical areas taking into consideration of characteristics of the rendition equipment (e.g., screen, printer) and the author's intentions expressed by layout styles associated with the logical objects. The logical tree is converted into a layout tree -- a tree-like structure of objects directly adapted to the imaging of the document. These objects are *page sets*, *pages* and objects within a page: *frames* and *blocks* [Ref. 19]. The layout structure of a document is illustrated in Figure 5.

The page set is a composite layout object that consists of one or more pages and/or one or more subordinate page sets, which need to be identified as a group.

A page is a rectangular area that corresponds to a unit of the presentation medium (e.g., printer, screen, plotter). It is the reference area used for positioning and imaging the content of the document.

A frame is a rectangular layout area within a page or within a frame of a higher hierarchical level. Frames define boundaries within a page for the layout of the content.

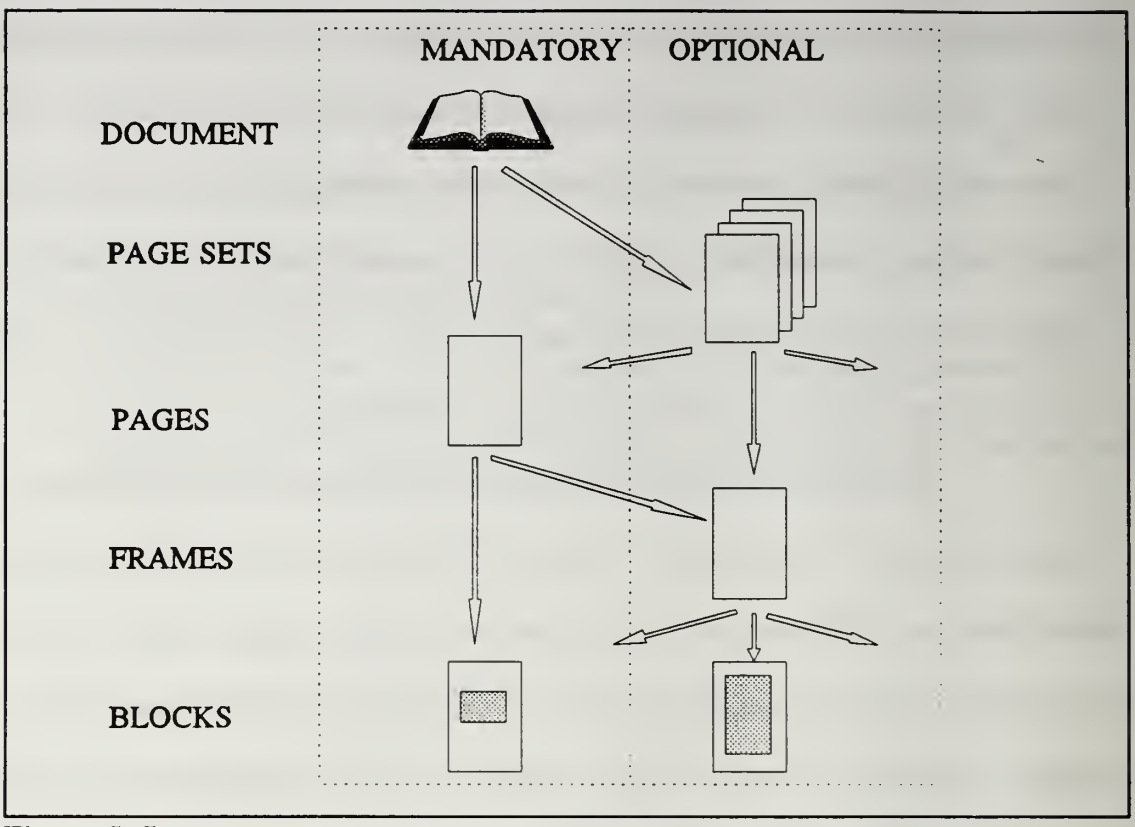

Figure 5. Layout structure

A block is a rectangular area containing one or more content portions of the same content architecture [Ref. 20].

4. Interchange format (ODIF and ODL)

ODA provides two formats for document interchange: Office Document Interchange Format (ODIF) and Office Document Language (ODL). ODIF was the only format for ODA document interchange (1984 standard) and later the second format, ODL, was added (1988 standard).

Both interchange formats work with three types of documents [Ref. 19, 22]:

- Processable document: the result of the editing process, which will be represented by logical objects whose content is revisable. It may be both edited and formatted. It is the form for the exchange of revisable documents without including

instructions for presentation. The logical generic structure and the styles can accompany the document during interchange.

- Formatted document: the result of the layout process, which will be represented by layout objects whose content is not itself revisable. This allows the interchange of the image of a finished document. The layout generic structure may sometimes accompany the document to factorize repetitive entities.

- Formatted processable document: the result of the editing and layout processes. For this category documents, there will be coexistence of both logical and layout structures. This form allows documents to be presented as well as edited and formatted. Contents will include marks which will identify commands added during the layout process.

a. ODIF

The Office Document Interchange Format defines the coding of objects, styles and contents of structure documents. The interchange format specifies two things: First, the sequence in which descriptors and text units appear (e.g., logical structure descriptors precede layout structure descriptors); second, the abstract syntax for interchange, as defined by ISO 8824 (Specification of Abstract Syntax Notation One: ASN.1) and CCITT X.419.

ODIF is a binary encoding of ODA documents. It is a machine-readable format designed for use in OSI network [Ref. 22]. Within a data stream, the information is ordered according to the rules of the standard. There are two sets of rules for ODIF: [Ref. 22]

- Interchange format class A: This set of rules is used to exchange any type of ODA document: formatted, processable, or formatted processable.

- Interchange format class B: This set does not support the generic or specific logical structures and is therefore only used to exchange formatted documents for presentation on recipient's system. This format is equivalent to sending a file in a page description language.

b. Office Document Language (ODL)

ODL is an Standard Generalized Markup Language (SGML)[2] application for describing ODA documents in human-readable format. ODL is technically equivalent to ODIF, but there are several significant difference.

- ODL can send a document which is divided into several files. In ODIF, a document must be sent as one complete file
- ODL provides a way of retaining the entire structure of a document using SGML syntax. In ODIF, all entities related to a document are transmitted as part of the itself such that there is no means of retaining the entire structure of a document.
- ODL transmits a document in human-readable clear-text format.
- ODL provides a more convenient way for publication industry and DoD which already make use of SGML.

5. Document processing

The document processing includes three processes: editing, layout, and image generation. The editing process is used to create or reprocess a document. The author manipulates the logical objects making up his document and the various contents associated with them. If a document conforms to a prerecorded document class, this is represented by a logical generic document class. Such a document is described by a logical generic structure which guides the editing process by requiring the author to respect the characteristics of the class [Ref. 19]. The layout process converts the logical structure of the document into a layout structure. Finally, the image generation process

---

[2] SGML is ISO standard 8879 (1986). It is a document representation language for describing information in a standard notation, or syntax. Currently, there are two public application of SGML in widespread use: one developed by the Association of American Publishers (AAP) for use in books and journals and one developed by the U.S. Department of Defense (DoD) for use in technical publications.

(presentation process) enables the document to be represented in a language adapted to the imaging environment. This process can compose the image of a page by positioning the character and graphic areas correctly and transfer the bitmap image of the page to a printer or screen. One can imagine translations of the layout structure into page description languages used today on various printers (e.g., PostScript, DDL)[Ref. 19]. Figure 6 shows the three processes of editing, layout, and image generation.

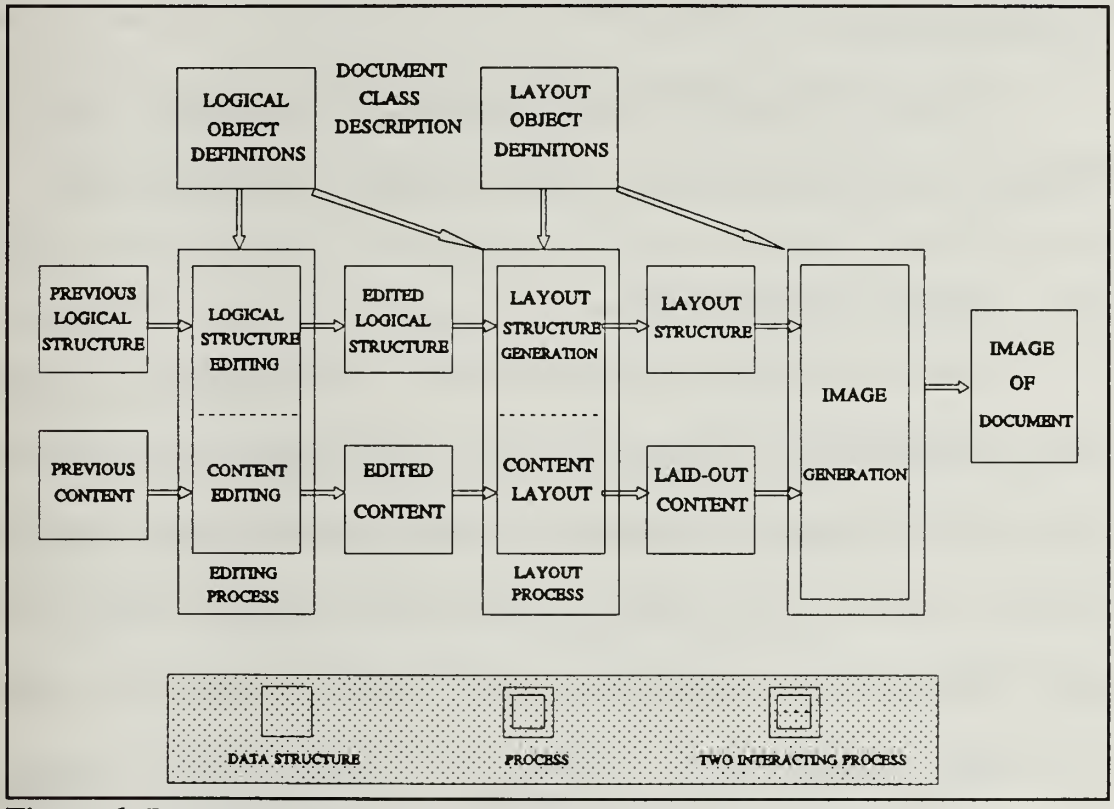

Figure 6. Document Processing Model [Ref. 20]

6. Content structure

The ODA document content includes characters, geometric graphics, and bitmap graphics. These are the basic contents which ODA currently supports. Chapter III will give more detailed discussions on each of these components.

III. ODA CONTENTS STRUCTURE AND ITS CODING

Until now, ODA allows formatted text, raster graphics, and vector graphics. But the future standards will include still image, motion video, and audio. Current ODA content standards approved by ISO are formatted text, TIFF (Tagged Image File Format) for raster graphics which is also standard format for Group IV FAX, and CGM for vector graphics.

This chapter will survey the general background and current status of each of these standard as well as future considerations for still image and full-motion video.

A. CHARACTER CONTENT

While character content architecture is based on several ISO and CCITT standards and recommendations[3], its basic architecture is ISO 8613-6 [Information Processing - Text and Office Systems-Office-Document Architecture (ODA) and Interchange Format - Part 6: Character Content Architectures] and CCITT Recommendation T.416 (Blue Book, 1988) [Open Document Architecture (ODA) and Interchange Format - Character

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[3] . ISO 2022 (1986): Information processing - ISO 7-bit and 8-bit coded character sets - Code extension techniques.
. ISO 6429 (1983): Information processing - ISO 7-bit and 8-bit coded character sets - Additional control functions for character imaging devices.
. ISO 6937 (1983): Information processing - Coded character sets for text communication.
. CCITT Rec. T.50 (1988): International alphabet No. 5.
. CCITT Rec. X.208 (1988): Specification of abstract syntax notation one (ASN.1).
. CCITT Rec. T.61 (1988): Character repertories and coded character sets for the international Teletex service.
. ISO 9541-5 (1991 DS): Information processing - Font and character information interchange - Font attributes and character model.

Content Architectures]. Character content part of ODA consists of fourteen sections dealing with character content formats, character positioning and imaging, attributes, definitions, control functions, layout and imaging process, etc.

As in ODA document, there are three classes of character content format: formatted, processable, and formatted processable. Formatted content is for layout and imaging of that content, but not for editing. Processable content is content which has not been laid out. Formatted processable content is content that is structured such that it contains both the formatted content and the processable content as subset.

The positioning of a character is decided by directions, position point, character baseline, and escape point. Start-aligned, end-aligned, centered, and justified provide alignment of a block. To support international language, it support reversed presentation direction.

Four groups of specifications apply to the imaging of graphic character elements. Those are emphasis, font selection, subscript and superscript, and character combinations. Methods of emphasis are weight (faint, normal intensity, and **bold**), posture (not italicized, *italicized*), underlining (not underlined, underlined, doubly underlined), Blinking (steady, slowly blinking, rapidly blinking), image inversion (positive image, negative image), and crossing-out (not crossed-out, ~~crossed-out~~). For font selection, the document profile specify the font used and characteristics. ODA character content architecture follows ISO font standard ISO 9541. $^{\text{Superscript}}$ and $_{\text{subscript}}$ is accomplished by partial line down (PLD), partial line up (PLU), line position backward (VPB), and line position relative (VPR) control functions.

B. RASTER GRAPHICS CONTENT

1. Background

Raster graphics part of ODA is Tagged Image File Format (TIFF) which supports high-resolution bit-mapped gray-scale and color images, with compression optional. Its related standards are CCITT recommendation T.4 (1988) [Standardization of Group 3 Facsimile Apparatus for Document Transmission], T.6 (1988) [Facsimile coding Schemes and Coding Control Functions for Group 4 Facsimile Apparatus] and X.208 (1988) [Specification of Abstract Syntax Notation One (ASN.1)]. There are two classes of raster graphics content architecture. One is formatted, which allows for document content to be presented as intended by the originator. Another class is formatted processable, which can be processed as well as be presented as intended by the originator.

2. Coding

Raster graphics content uses following encoding schemes:

- Group 4 facsimile encoding scheme (CCITT Rec. T.6)
- Group 3 facsimile encoding scheme (CCITT Rec. T.4)
- bitmap encoding scheme

CCITT Rec. T.6 specifies the principle of the Group 4 coding scheme as follows:

> The coding scheme uses a two-dimensional line-by-line method in which the position of each changing picture element on the current coding line is coded with respect the position of a corresponding reference element situated on either the coding line or the reference line which is immediately above the coding line. After the coding line has been coded, it becomes the reference line for the next coding line. The reference line for the first line in a page is an imaginary white line.

The coding line is referenced to previous line and run length is decided by three coding modes (pass, vertical, and horizontal mode). Then, the run length is translated into codeword.

The Group 3 apparatus uses one-dimensional run length coding scheme. Rec. T.4 describes its coding scheme as follows:

> A line of data is composed of series of variable length code words. Each code work represents a run length of either all white or all black. White runs and runs alternate. A total of 1728 picture elements represent one horizontal scan line of 215 length. The code words are of two types: Terminating code words and Mark-up code words. Each run length is represented by either one Terminating code word or one Mark-up code word followed by a Terminating code word.

Another coding scheme used in Group 3 facsimile is two-dimensional coding which is optional and identical to Group 4 facsimile coding scheme.

Third encoding scheme is bitmap encoding in which each pixel or element is mapped with one-to-one way. Each element is represented by a single bit which has value '0' or '1' depending on the state of the element (pixel). The resulting array of bits which represents a row is encoded by a string of octets. If the number of bits in each row of the array is not a multiple of eight, then it is extended by the minimum number of '0' bits such that the last bit aligns on an octet boundary.

3. Compression

Currently, both hardware and software compression provide maximum of 255:1 compression ratio on bitmapped file [Ref. 31].

4. Current status

TIFF file format is widely accepted and the majority of graphics applications provides import and/or export of this file format both in PC and Apple computer.

C. VECTOR GRAPHICS CONTENT

1. Background

A graphical metafile is a mechanism for the capture, storage, and transport of graphical information [Ref. 51]. It provides a data format for picture archiving, a single standard interface to picture-generating devices, and the glue for unifying and integrating distinct graphics applications and hardware/software systems in a distributed computing environment. Figure 7 illustrates functions of Computer Graphics Metafile (CGM) related to graphics application environment.

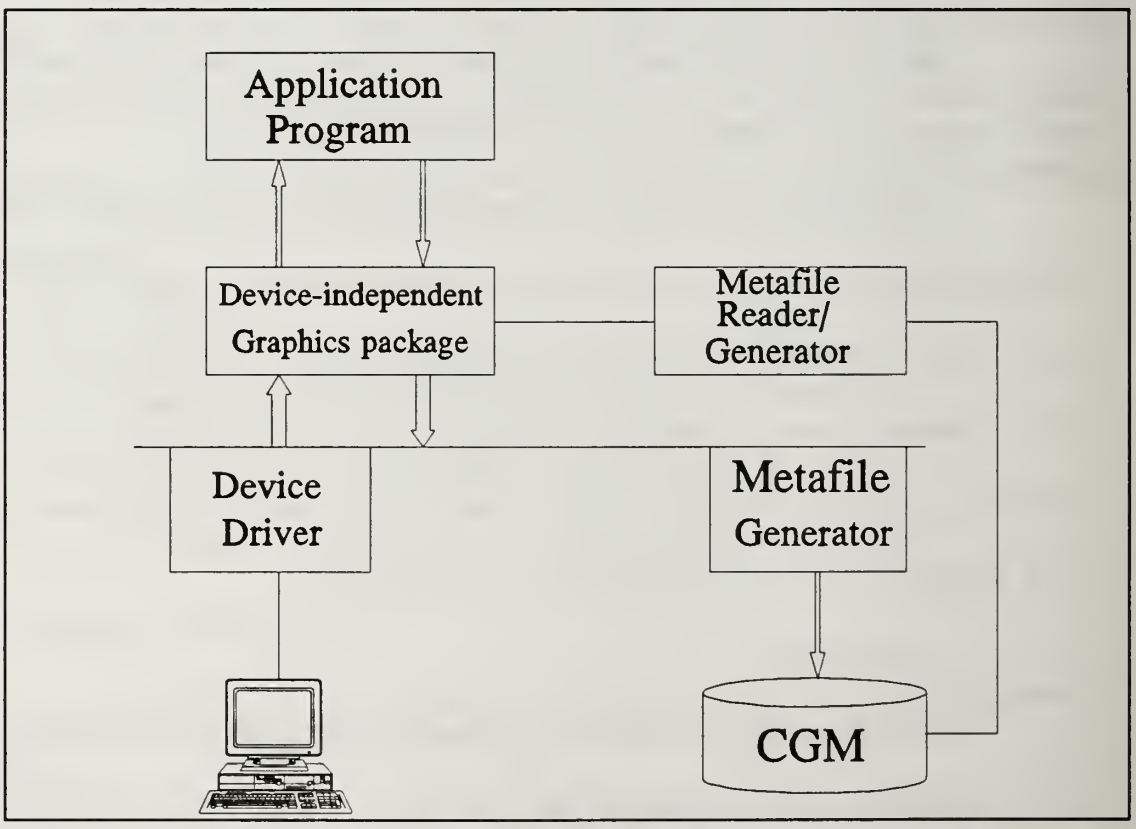

Figure 7. CGM and its relation to graphics application environment

The CGM is the ISO standard that defines the functionality and encoding for pictures stored on computer systems [Ref. 55]. It is a component standard of ODA

documents consisting of text, raster graphics, and vector graphics. CGM for the storage and transfer of picture-description information enables pictures to be recorded for long-term storage, to be exchanged between graphics devices, systems and installations.

In October 1981, ISO TC97/SC5/WG2 [Computer Graphics] established a metafile subgroup that was given the task of:

- developing a framework in which graphical metafiles can be studied, developed and related to other standards;
- designing a metafile standard proposal and recommending whatever 'work items' would be needed in this area to produce the desired standard.

The history of standardization is well described in [Ref. 43].

> The metafile subgroup had its first meeting in 1882. The aim of this project was to create a system-independent graphics metafile that can be used with a wide range of systems and devices. The subgroup has based its work on experiences with various metafiles and Graphics Kernel System (GKS) and its metafile. However, the greatest impact has come from the metafile group of the American National Standards Institute (ANSI) X3H33. The group has been developing a national U.S. standard for a metafile that originally called "Virtual Device Metafile VDM" [ANSI82]. Meanwhile, the ISO metafile project has been names "Computer Graphics - Metafile for the Storage and Transfer of Picture Description Information (CGM)". The CGM is a basic metafile containing static consistent pictures without a picture structure and without a dynamic picture change facility. The CGM is defined in a multi-part standard (ISO 8632/1 to ISO8632/4, currently 1985 at DIS stage [ISO85c]). Part 1 of the standard defines the CGM functionality, Part 2 contains a character coding based on ISO 2022 code extension techniques, and Part 3 defines a binary coding. In part 4, a clear text coding which can be written, read, and edited in the same way as plain text is specified.

The CGM standard was published as an ISO standard in 1987. In the United States, American National Standard Institute (ANSI) published it as ANSI X3.122-1986. The U.S. government adopted the CGM as a Federal Information Processing Standard (FIPS) 128 [Computer Graphics Metafile (CGM)] in March 1987, and the Department of Defence (DoD) published a military specification MIL-D-28003 [Digital

Representation for Communication of Illustration Data: CGM Application Profile] in December 1988. Also, it has been given a considerable push towards very wide acceptance by its adoption within the DoD Computer-Aided Acquisition and Logistics Support (CALS) initiative.

2. Coding

Pictures are described in the CGM standard as a collection of elements of different kinds, representing, for example, primitives, attributes, and control information. CGM is a static picture capture metafile, which means it contains no elements with dynamic effects on partially defined picture.

The CGM standard consists of four parts; Part 1: elements and structure, Part 2: character encoding, Part 3: binary encoding, and Part 4: clear text encoding.

- Part 1 is a functional specification. All standardized elements are identified, their parameterizations are described, and their meanings are defined.

- Part 2 defines a character encoding of graphics metafiles. Opcode and parameter data are encoded by characters from ASCII (ISO 2022) character set. The resulting encoded data consists of printable characters. The encoding is compact and can be transmitted directly through standard character-oriented communications services.

- Part 3 defines a binary encoding of graphics metafiles. It is intended for applications in which speed of generation and speed of transmission are most important. The format for encoded data are either chosen for their similarity to data formats in computers, or designed for fast decoding and processing.

- Part 4 defines clear text encoding of graphics metafiles. It is human readable format. It is transmissible with standard character-oriented services, but is not very compact and relatively slow to generate and interpret. An important feature is its ease of comprehension and manipulation using standard text editors. It has a format-free notation, comparable to modern, high-level programming language syntax.

A CGM is structured as a series of levels: metafile level, picture level, and picture body level. A metafile consists of a metafile descriptor and several picture descriptions. The metafile descriptor contains information valid for the whole metafile -- version of a metafile, metafile description. Picture descriptions are self-contained. Pictures are bounded by picture-by-picture delimiters. A picture starts with a picture descriptor that contains information about how this particular picture is stored and information about scaling for specific device. Picture body contains the definition of the picture, describing the graphical content of the picture. The graphical primitive elements defines the geometric objects that make up the picture -- lines, text, circles, curves, etc. CGM contains a rich set of primitives for lines, markers, filled areas, text, and generalized raster function. The structure of CGM is illustrated in Figure 8.

For color attributes, CGM provides two modes of color specifications - indexed and direct. In indexed mode, color is selected by pointing to a color table located at each workstation. For each COLOR INDEX value, the color table contains an entry which specifies color in terms of Red/Green/Blue (RGB) intensities in the range [0, 1]. In direct mode, the parameters of the color-specification elements are RGB triples. Initially, CGM only supported RGB color specification. But in later amendment (amendment 3), CGM was enhanced to support CYMK (Cyan/Yellow/Magenta/Black) and CIE (Commission Internationale L'Eclairage) color models.

CGM specifies three ways of encodings, i.e. character, binary, and clear-text, for the functional description. The character encoding uses American Standard

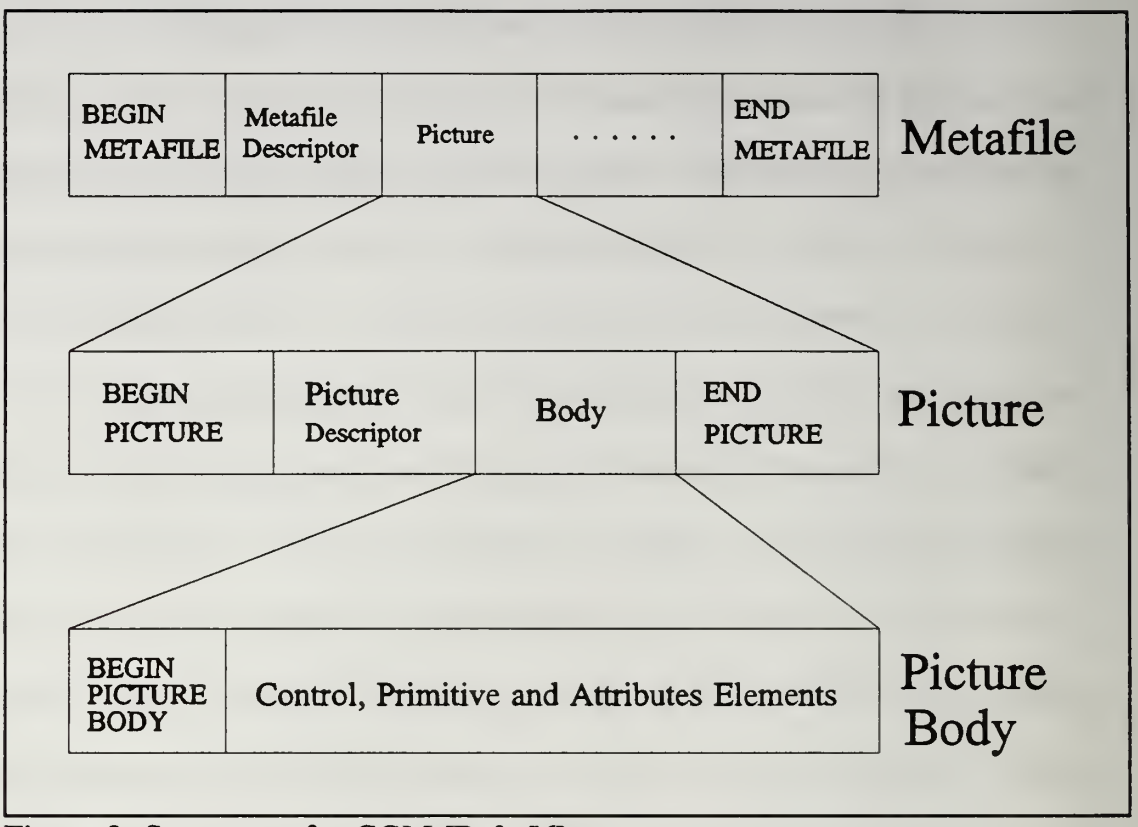

Figure 8. Structure of a CGM [Ref. 56]

Code for Information Interchange (ASCII) printing characters, the binary encoding uses 8-bit bytes, and the clear-text encoding is human-readable. A metafile in one encoding can be translated to another encoding without loss of information. A number of graphics packages can read in a CGM in one encoding, and output it in another. There are also graphics utilities that can convert one encoding to another. The methods, advantages and disadvantages of each encoding methods are summarized in Table 1.

Table 1. CGM ENCODING

	character encoding	binary encoding	clean-text encoding
encoding method	ASCII printing characters	8-bit byte	clear-text (human readable)

advantages	. concise . can be transmitted over any network	. easier . quicker . fairly concise	. can be edited with normal text editor
disadvantage	. require more processing time	. cause problems for some networks	. not concise

3. Compression

The compression of CGM has less significance than the compression of raster graphics or full-motion video because the size of a CGM metafile is relatively small compared to other components, and the compression ratio can vary with the encoding methods. Arnold, Liapakis, Reynolds, and Vezirgiannis [Ref. 56] conducted experiments on the efficient encoding of metafiles for transmission over network. To reduce the overall length of a metafile, they tried reordering the elements, delaying of the encoding of an attribute change until such time as a primitive element that uses the attribute is encountered, and catchall shorthand for the encoding of a metafile element list by setting it to DRAWING PLUS CONTROL SET. They devised, implemented, and tested the compression techniques for the binary encoding. The result is that an average of 9 % of space was saved.

Another consideration can be given to the compression of metafile itself. Current data compression utilities[4] can give from roughly 2:1 to 3:1 compression on clear-text files. In the cases of character and binary encoding, the range of compression

[4] Reduce, Stacpack, PKZIP, ARJ221A, LHA213, and PAK251

ratio roughly varies between 1:1 and 3:1. If CGM specific compression technique is devised, the ratio will be greater.

4. Current status

Currently, there are a number of ISO and ANSI graphics standard, including Initial Graphic Exchange Specification(IGES), Graphical Kernel System (GKS), GKS-3D (GKS-dimensional), CGM, and Programmers' Hierarchical Interactive Graphics System (PHIGS). Among them, CGM gets wide a support from industry and government sectors. The wide adoption of CGM as a graphics standard is demonstrated by the following events:

- CGM was adopted as the picture-defining protocol of ODA.
- In March 1987, the U.S. government announced its adoption of CGM as the Federal Information Processing Standard (FIPS 128) [Ref. 52].
- In December 1988, U.S. DoD published its military specification MIL-D-28003 [Digital representation for communication of illustration data: CGM application profile.] [Ref. 48].
- In May 1991, the U.S. government starts the CGM test service to determine whether the CGM format is both successful and a practical method of sharing images across diverse computer platform.

On the other side, the CGM is revised to provide the needs of application groups. The first amendment was done in 1990 and third amendment is in process.

D. STILL IMAGE

1. Background

Still-image is one of the components to be included in ODA. The problem with still-image consists in its vast amount of data to transmit and store. For example,

a frame of CCIR (A-601) digital studio video signal, represented by 720 x 486 pixels and 16 bits per pixel, amounts to approximately 5.6 Mbits in an uncompressed form.

Modern image compression technology offers a solution to this problem. State-of-the-art technology can compress typical images by a factor of 10:1 through 50:1 without visibly affecting image quality [Ref. 61]. But compression only is not sufficient for modern open system environment in which interoperability is the major concern. The receiver is supposed not to worry about what compression technique and equipment sender uses. A standard compression method is needed to ensure interoperability of equipment from different manufacturers.

Formal effort for still-image coding started at the end of 1986. Experts from both the CCITT and ISO groups met to form the Joint Photographic Experts Group (JPEG). They tasked themselves with the selection of a high performance universal compression technique [Ref. 58]. The relationship between CCITT, ISO, and JPEG is illustrated in Figure 9.

The first image quality evaluation took place in June 1987 at the Copenhagen Telephone Company (KTAS) research lab. Out of the twelve proposed techniques, ten

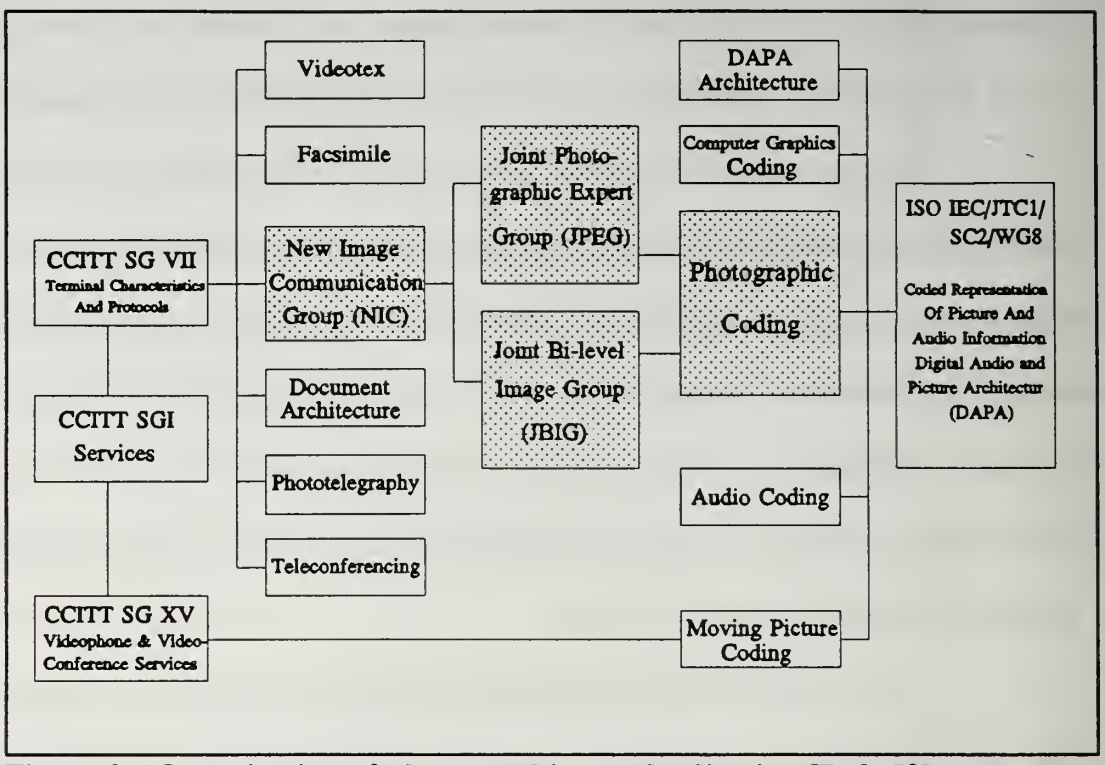

Figure 9. Organization of photographic standardization [Ref. 58]

techniques were tested at the evaluation[5]. The selection procedures are well described in [Ref. 58] and [Ref. 59]. The finalists were the Adaptive Discrete Cosine Transform (ADCT), the Adaptive Binary Arithmetic Coder (ABAC), and the Block Separated Component Progressive Coding (BSPC). BSPC is based on GBTC and PCS. The second selection process took place in January 1988 at the same place, and resulted in

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[5] DCTV (Discrete Cosine Transform with Vector Quantization)
ADCT (Adaptive Discrete Cosine Transform)
DCTD (Adaptive DCT and Differential Entropy Coding)
BCTF (16 x 16 DCT with Filtering)
BLT (Block List Transform)
PCS (Progressive Coding Scheme)
PRBN (Progressive Recursive Binary Arithmetic)
ABAC (DPCM Using Adaptive Binary Arithmetic)
GBTC (Generalized Block Truncation Coding)
CVQ (Component Vector Quantization)

the selection of ADTC for final refinement, with the goal of producing and ISO Draft Proposal by February 1989 [Ref. 59].

2. Coding

The proposed standard contains the four modes of operation [Ref. 61]:

- Sequential encoding: Each image component is encoded in a single left-to-right, top-to-bottom scan.
- Progressive encoding: The image is encoded in multiple scans for applications in which transmission time is long, and the viewer prefers to watch the image build up in multiple coarse-to-clear passes.
- Lossless encoding: The image is encoded to guarantee exact recovery of every source image sample value (e.g., as required by medical applications).
- Hierarchical encoding: the image is encoded at multiple resolutions, so that lower-resolution versions may be accesses without first having to decompress the image at its full resolution.

Based on these modes of operation, different kinds of codecs (encoder/decoder) are specified. All of these codecs are variations of the JPEG baseline model to ensure the operation with various image formats across applications. For the DCT sequential-mode codecs, the baseline model shows almost complete coding process. For the DCT progressive-mode codecs, the image buffer exists prior to the entropy coding step, so that an image can be stored and then parcelled out in multiple scan with successively improving quality. For the hierarchical mode of operation, the baseline model is used as a building block within a larger framework.

The JPEG baseline model consists of 3 steps -- transformation, quantization, and lossless entropy coding as shown in Figure 10. At the input to the encoder, source image samples are grouped into 8 x 8 blocks and precessed by the Forward Discrete

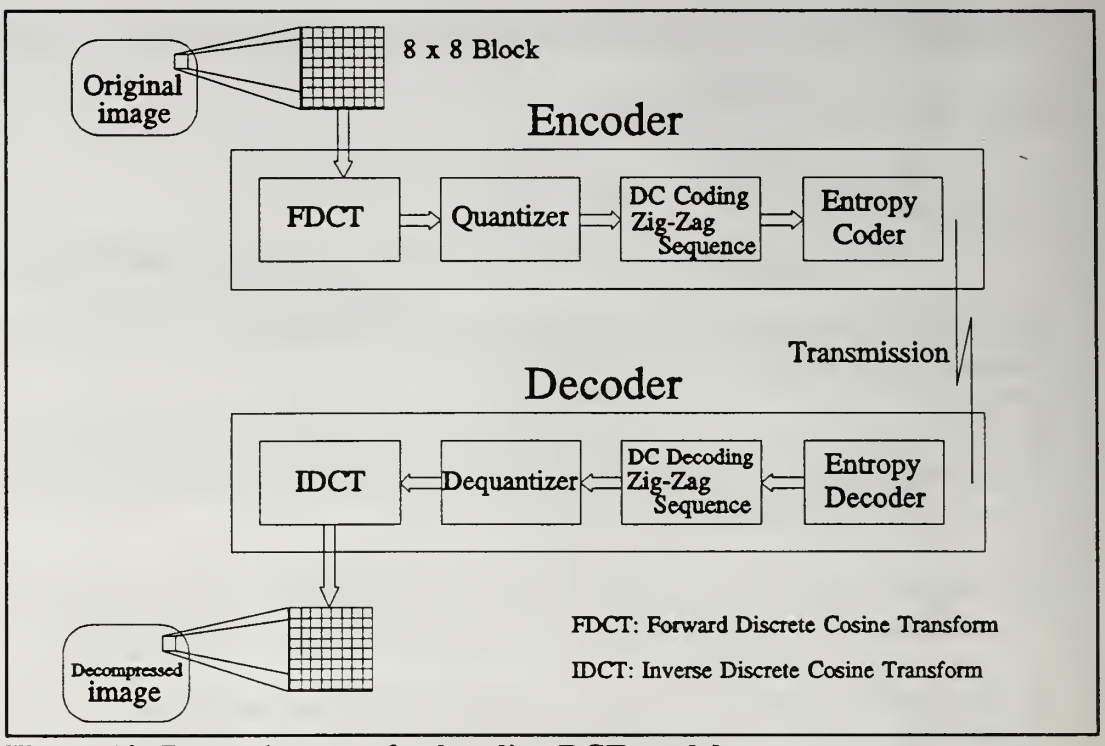

Figure 10. Processing step for baseline DCT model

Cosine Transform (FDCT). Following is the description of the DCT part of JPEG codecs [Ref. 61].

> The DCT is related to Discrete Fourier Transform (DFT). Each 8 x 8 block of source image samples is effectively a 64-point discrete signal which is a function of the two spatial dimensions x and y. The FDCT takes such a signal as its input and decomposes it into 64 orthogonal basis signals. . . . The output of the FDCT is the set of 64 basis-signal amplitudes or "DCT coefficients" whose values are uniquely determined by the particular 64-point input signal. . . . At the decoder, the IDCT reverses this processing step. It takes the 64 DCT coefficients (which at that point have been quantized) and reconstructs a 64-point output image signal by summing the basis signals.

The following equations are the idealized mathematical definitions of the 8 x 8 FDCT and IDCT:[Ref. 61]

The next step is quantization which quantizes the DCT coefficients to reduce their magnitude and to increase the number of zero value coefficients. The quantization

$$F(u,v)=\frac{1}{4}C(u)C(v)[\sum_{x=0}^{7}\sum_{y=0}^{7}f(x,y)\cos\frac{(2x+1)u\pi}{16}\cos\frac{(2y+1)v\pi}{16}]$$

$$f(x,y)=\frac{1}{4}[\sum_{u=0}^{7}\sum_{v=0}^{7}C(u)C(v)F(u,v)\cos\frac{(2x+1)u\pi}{16}\cos\frac{(2y+1)v\pi}{16}]$$

$$\textit{where}\quad C(u) = C(v) = \frac{1}{\sqrt{2}}\quad \textit{for}\ u = v = 0;\ C(u) = C(v) = 1\quad \textit{otherwise}$$

method used in JPEG is uniform midstep quantization, where the step size varies according to the coefficient location and which color component is encoded. The purpose of quantization is to achieve further compression by representing DCT coefficients with no greater precision than is necessary to achieve the desired image quality. It is the principle source of lossiness in DCT-based encoders[Ref. 61].

Followed by quantization, DC coding and zig-zag sequence is applied. This step rearranges quantized DCT coefficients into a zig-zag pattern, with lowest frequencies first and highest frequencies last. The zig-zag pattern is used to increase the run length of zero coefficients found in the block.

Next, the DC and AC coefficients are losslessly encoded, both using Huffman-style coding but keyed with different parameters. Huffman coding is a well known means of reducing the number of bits needed to represent a data set without losing any information and is easy to implement in hardware. To compress data symbols, the Huffman coder creates shorter codes for frequently occurring symbols and longer codes for occasionally occurring symbols. The resulting data is passed to the host bus for storage or transmission.

3. Compression

For color images with moderately complex scenes, all DCT-based modes of operation typically produce the following levels of picture quality for the given range of compression. (The units "bits/pixel" means the total number of bits in the compressed image - including the chrominance components - divided by the number of samples in the luminance component.) [Ref. 61]

- 0.25-0.5 bits/pixel: moderate to good quality, sufficient for some applications;
- 0.5-0.75 bits/pixel: good to very good quality, sufficient for many applications;
- 0.75-1.5 bits/pixel: excellent quality, sufficient for most applications;
- 1.5-2.0 bits/pixel: usually indistinguishable from the original, sufficient for the most demanding applications.

A sample still-image with resolution of 720 x 486 and 16 bits per pixel -- 8 bits for luminance and 8 bit for chrominance components -- will take up 5,598,720 bits of storage without compression. Table 2 summarizes the relationship between "bits/pixel" representation and compression ratio for this sample image.

Table 2. COMPRESSION RATIO FOR EACH BITS/PIXEL REPRESENTATION

bits/pixel	Original image size (bits)	Compressed image size (bits)	Compression ratio
0.25	5,598,720	87,480	64:1
0.50		174,960	32:1
0.75		262,440	21.3:1
1.00		349,920	16:1
1.50		524,880	10.7:1
2.00		699,840	8:1
16.0		5,598,720	1:1

4. Current status

Solutions for JPEG were offered first by C-Cube Microsystems Inc., San Jose, Calif., then by LSI Logic Corp., Milpitas, Calif [Ref. 67]. The first single-chip image compression/decompression device CL550 from C-Cube Microsystems is 380, 000-transistor chip. CL550 can compress or decompress a full-page, 24-bit color, 300 dpi (dot per inch) image in less than one second, reducing the 25 megabyte original bit-map image to under 1 megabyte with no visible degradation. A 640 x 480 resolution 24-bit screen image can be compressed by a factor of ten in less than one-thirtieth of a second, making real-time, full-motion compression feasible.

E. MOTION VIDEO: MPEG (Moving Picture Experts Group)

1. Background

Full-motion video will be the most demanding component of compound document. The problem with full-motion video stems from its vast amount of data to be processed and transmitted, which will severely strain CPU, storage, network resources. For example, a frame of CCIR digital studio video (A-601) generates 5.6 megabits when uncompressed. For 30 frames per second video, the amount of data to represent one second of motion comes up to 168 megabits. Liebhold and Hoffert [Ref. 72] compared the cost between voice and video transmission. Digital video running at 1 megabits per second bandwidth (compressed) would cost $1,000 per hour, compared with voice running at 10 kilobits per second costing $10 per hour, assuming a coast-to-coast connection.

Some of the standards for full-motion video are shown [Ref. 64, 65, 66, 70, 72, 79] in Table 3.

Table 3. FULL-MOTION VIDEO STANDARD

Name	Organization	Bandwidth	Applications
H.261	CCITT	64 kbps x p (p=1 .. 30)	Video Phone, Video Conference
MPEG	ISO	1.5 Mbps	CD-ROM, ISDN, LAN
CD-I[6]	Industry	1.4 Mbps	Consumer Electronics
CMTT/2[7]	CCITT/CCIR	34 Mbps/45 Mbps	Digital TV, HDTV
DVI[8]	Intel	1.5 Mbps	Desktop video

It is believed that MPEG will become the standard for the motion video component of ODA document. MPEG standard is known by the name of the expert group that started it: Moving Picture Experts Group which is part of the ISO-IEC/JTC1/SC2/WG11 [Ref. 69]. Formal standardization efforts started in 1988 with the goal of achieving a draft standard by 1990. After satisfying the requirements for the standard, the selection process was begin. Seventeen companies or institutions contributed or sponsored a proposal, and fourteen[9] different proposals were presented

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[6] Compact Disc-Interactive (CD-I)

[7] Committee on Mix of Telephone and Television

[8] Digital Video Interactive (DVI)

[9] AT&T (USA), Bellcore (USA), Intel (USA), GCT (Japan), C-Cube Microsystem (USA), DEC (USA), France Telecom (France), Cost 211 Bis (EUR), IBM (USA), JVC Corp (Japan), Matsubisi EIC (Japan), Mitsubisi EC (Japan), NEC Corp (Japan), NTT (Japan), Philips (Netherlands), Sony Corp (Japan), Telenorma/U. Hannover (Germany)

and subjected to analysis and subjective testing. Those proposals were tested and integrated into the Committee Draft in September 1990.

2. Coding

The industry- and sponsor-contributed proposals are representing the interests of their own field-- telecommunications, hardware, computer systems, consumer electronics, and TV broadcasting. The coding method should be selected in such a way that it can support a wide range of applications. For instance, video on digital storage includes the following applications:

- Asymmetric Applications (one time compression, frequent decompressions): electronic publishing, education and training, point of sales, videotext, games, and entertainment (movies)

- Symmetric Applications (equal use of compression and decompression): electronic publishing (production), video mail, videotelephone, and video conferencing.

Each application requires specific features in the coding algorithm. For example, commercial video disc systems may need features of still frame, video-audio synchronization, and fast forward/reverse search, but may not need the editability feature. To fulfil requirements of various applications, MPEG defined a set of features to be satisfied by its compression algorithm. These features are;

- Random access: Random access requires that a compressed video bit stream be accessible in its middle and any frame of video be decoderable in limited amount of time (1/2 second).

- Fast forward/reverse searches: It should be possible to scan a compressed bit stream and, using the appropriate access points, display selected pictures to obtain a fast forward or fast reverse effect.

- Reverse playback: Interactive application might require the video signal to play in reverse.

- Audio-vidual synchronization: The video signal should be accurately synchronizable to an associated audio source.

- Robustness to errors: The source coding scheme should be robust to any remaining uncorrected errors; thus catastrophic behavior in the presence of errors should be avoidable.

- Coding/decoding delay: The algorithm should perform well over the range of acceptable delays and the delay is to be considered a parameter (e.g., video telephone - maximum 150 millisecond; publishing application - maximum 1 second).

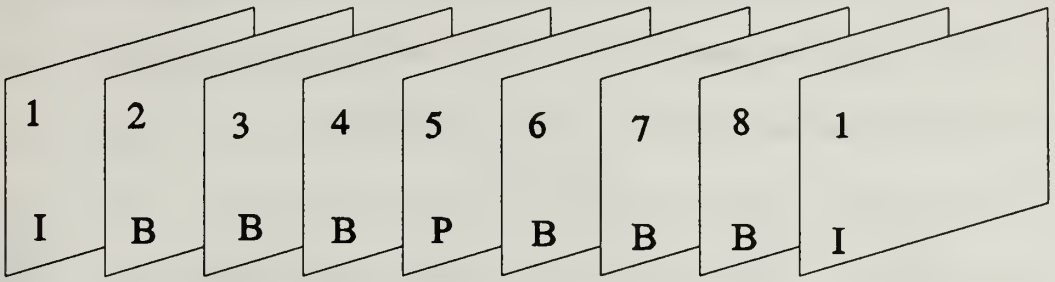
- Editability: It is desirable to be able to edit units of a short time duration.

- Format flexibility: The coding algorithm should handle wide range of formats (width and height) and frame rate.

- Cost tradeoffs: The algorithm should be implemented with a small number of chips, and the coding process could be performed in real time.

To satisfy both high compression ratio and the random access requirements, MPEG uses a combination of intraframe and interframe coding methods. The method used for intraframe coding is DCT and those for interframe are predictive coding and interpolative coding. MPEG uses three types of pictures: intrapictures, predicted pictures, and bidirectional pictures. Intrapicture provides the random access points and reference points to both predicted pictures and bidirectional pictures. Figure 11 shows the relationship between three types of pictures.

For interframe coding, MPEG uses motion-compensated prediction and motion-compensated interpolation. Motion-compensated prediction is the most widely used techniques that exploit the temporal redundancy of video signals [Ref. 69]. It assumes that "locally" the current picture can be modeled as a translation of the picture at some previous time. Motion-compensated interpolation is a technique that helps satisfy



	I: Interpictures	P: Predicted Pictures	B: Interpolated Pictures
Function	Provides access points for random access	Reference for future predicted picture	Not used for reference
Compression Ratio	Moderate	High	Highest
Reference picture	None	A past picture (Intra- or Predicted)	Both a past and a future picture (Intra- or Predicte

Figure 11. Three types of pictures

some of the application-dependent requirements since it improves random access and reduces the effect of errors while at the same time contributing significantly to the image quality.

The basic motion-compensation coding unit used in MPEG is a 16 x 16 block (microblock) which has types of intra, forward predicted, backward predicted, and average. The motion information associated with microblock is coded differently with respect to the motion information present in the previous adjacent microblock. The differential motion information is further coded by means of variable-length code to provide a greater efficiency.

As in JPEG standard, MPEG uses 8 x 8 DCT (Discrete Cosine Transform) to reduce spatial redundancy. Next, DCT coefficients are quantized. Because MPEG has both intra-coded picture and differentially-coded picture, it uses different quantizer for each block. While both quantizers have a constant step size, their step size around zero is different. Quantizer for intracoded blocks has no deadzone (i.e., the region that gets quantized to the level zero is smaller than a stepsize) while quantizers for nonintrablocks have a large deadzone. Quantized coefficients are further compressed by entropy coding step. To reduce the impact of the motion information on the total bit rate, variable-length coding is used. The variable-length code associated with DCT coefficients is a superset of the one used in CCITT recommendation H.261 to avoid unnecessary costs when implementing both standards on a single chip [Ref. 69]. The coding process is illustrated in Figure 12.

3. Compression

The bandwidth for transmission or storage of full-motion video depends on the source video format and compression ratio. For example, NTSC-like picture quality, assuming 480 x 270 pixels, 30 frames per second, and 16 bits per pixel, will consume about 62 Mbps transmission bandwidth. With 50:1 compression, the bandwidth required will be about 1.244 Mbps.

The premise of MPEG is that a video signal and its associated audio can be compressed to a bit rate of about 1.5 Mbps with an acceptable quality. The quality of video compressed with the MPEG algorithm at rate of about 1.2 Mbps has often been compared to VHS recording. For most source materials, artifact-free renditions can be

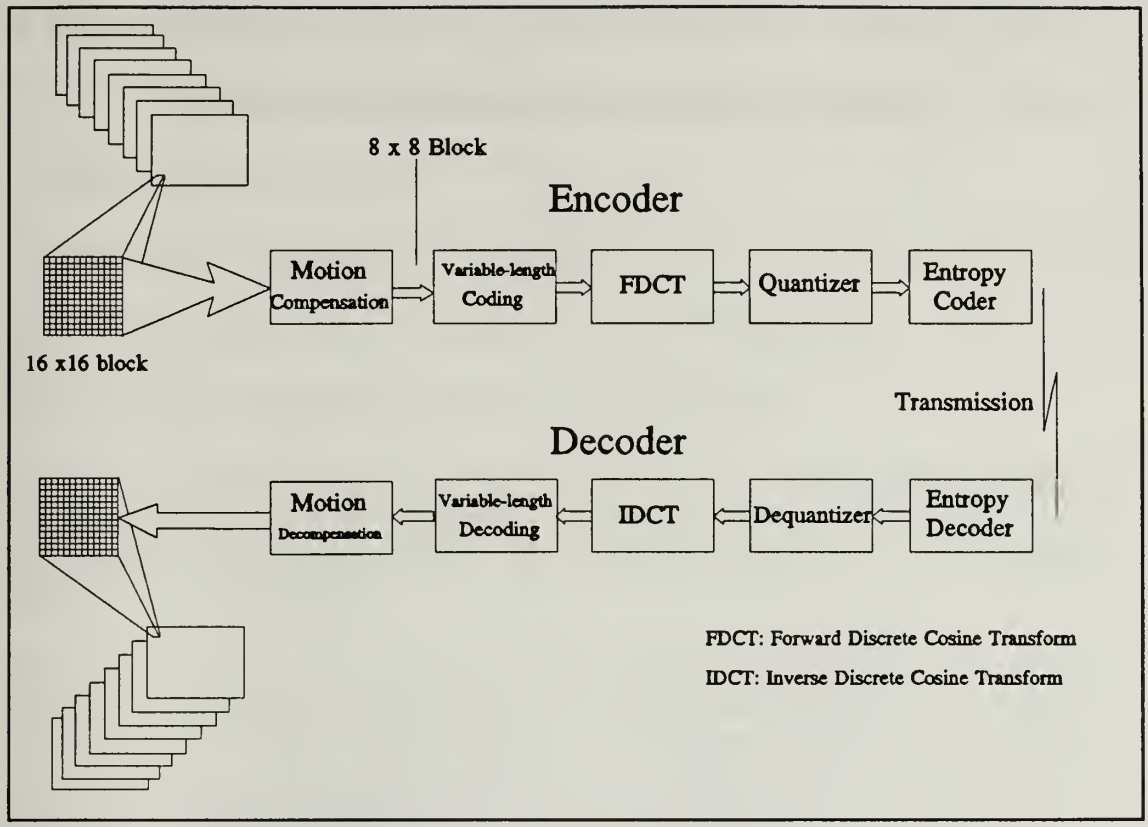


Figure 12. MPEG Coding process

obtained; but for the most demanding material, it is at times necessary to trade resolution for impairments [Ref. 71]. MPEG is not restricted to any given bandwidth. In fact the baseline standard is specified to operate up to 2.1 Mbps.

4. Current status

The MPEG standard is still in draft form, but it has wide support, including Apple, IBM, Sun, and Intel. C-Cube Microsystems became the first company to publicly demonstrate an MPEG decoder chip [Ref. 78]. The MPEG decoder is based on a programmable processor which enable changes in the standard by modifying the RAM-based microcode. The processor supports two modes: MPEG and JVC Extended mode. In MPEG mode, video can be compressed at rates of up to 200:1 and resolutions of up

to 704 by 576 pixels. JVC Extended mode, which is being developed with Victory Company of Japan Ltd., offers compression rates up to 50:1 [Ref. 79].

IV. MODELING OF MULTIMEDIA NETWORK

A. PROBLEM DEFINITION

Radding [Ref. 13] described one of the future military applications of multimedia network. The setting is one of perspectives of the Department of Defence CALS (Computer-Aided Acquisition and Logistic Support) initiative.

> A jet aircraft technician peers into the bowels of a malfunctioning engine, searching for the source of the problem. Finally, he spots it. Buried deep within the engine is the troublesome part. He will have to replace it. A complicated procedure, to say the least.
>
> The technician goes to his high-powered workstation attached to a network and calls up the information on the part and the replacement procedure. An image of the part seated in the engine appears. In another window, an instructor demonstrates the repair procedure in full-motion video while the technician listens through the audio channel as the instructor explains the process. Diagrams pop up to further clarify key points. In a text window, he reviews lists of necessary parts and tools he will need to complete the repair.
>
> Still confused about an irregularity in this situation, the technician presses the help key and a real-time image of a live supervisor pops up in another window. Using the attached microphone, the technician discusses the particular problem with the supervisor, who directs more information onto the technician's screen. The technician points a video camera at the part in question to show the supervisor the specific situation.

Implementation of such a system is possible with today's technology, but the lack of standards is the major barrier. The realization of importance of standardization led the industry and the standard organizations to the standardization of multimedia network and multimedia applications as we saw in Chapters II and III.

In addition to the standardization efforts, one of the problems with above scene is the vast amount of data storage and transmission bandwidth. In particular, formatted

text, raster graphics, vector graphics, still image, and full-motion video will significantly influence the performance of local area networks (LANs) and telecommunication networks. The typical transmission bandwidth or storage requirements for each component of multimedia e-mail are summarized in Table 4.

Table 4. STORAGE REQUIREMENTS FOR MULTIMEDIA E-MAIL COMPONENTS

Coding Format	Original Size (a page, frame, or 1 second of frames)	Compressed Size (page, frame, or 1 second of frame)	Compression Ratio
Text	24-32kbits (clean text) 80-160kbits (formatted text: WP5.1 file with style)	1-2 k	2.0-3.0
Raster Graphics (bi-level)	200dpi: 4,036,608 300dpi: 8,960,000 400dpi: 16,146,432	297,769 442,217 593,226	13.56 20.26 27.22
CGM	several 100 kbits to several Mbits	depends on coding (binary,character, or clean text coding)	1-3
JPEG (CCIR A-601 format) (multi-tone color)	5.6 Mbits/frame	112-560 kbits/frame	10-50
MPEG (NTSC quality)	62 Mbits/sec	1.5 Mbits/sec	50-150 (vary with frame by frame)

Current networks are able to support formatted text, bi-level raster graphics, and some vector graphics effectively. But multi-tone color raster graphics, complex vector graphics, and full-motion video can be a disastrous source of network bottleneck.

Therefore the design of multimedia applications must be preceded by a careful analysis of network performance in relation to their bandwidth requirements.

There have been some studies on multimedia data transmission on LANs [Ref. 84 - 89]. Chen and Lu [Ref. 84] analyzed the integrated voice and data transmission on CSMA/CD network. Mark and Lee [Ref. 85] proposed a dual-ring LAN for integrated voice/video/data services that have different communication service requirements (i.e., synchronous and asynchronous). Deng, Chiew, and Huang [Ref. 88] investigated the performance of token-ring LANs with multimedia file transfer.

Related to these studies, we develop a simulation model to analyze the performance of multimedia LAN. The primary purpose of this simulation model is to examine the effect of the multimedia data traffic, especially high-resolution still-images, on the performance of LAN. Another consideration is that the adoption of current compression technologies into the model for still-image compression.

B. SYSTEM DEFINITION AND MODEL FORMULATION

1. System definition

Within an office information system or military application as we saw in the above scenario, an image browsing activity is an important part of LAN usage. An image browsing activity may require transfer of a large volume of information in a short period of time.

Currently, the LAN standards are categorized into three LAN types: CSMA/CD bus, token bus, and token ring. CSMA/CD bus LANs are specified by IEEE 802.3 standards and currently have five options: 10BASE5 (Ethernet), 10BASE2

(thin Ethernet), 1BASE5, 1BASET, and 10BROAD36. Token-ring LANs include IEEE 802.5 4Mbps, IEEE 802.5 16Mbps, and ANSI's Fiber Distributed Data Interface (FDDI) 100Mbps. Lastly, token-bus LANs are specified by IEEE 802.4 standards and have a few options. We selected token-ring LANs for our simulation study because of their support of a wide range of transmission speed (4, 16, and 100 Mbps), their efficient operation at very high data rates, and the ability to readily accommodate fiber.

The token-ring network has stations actively coupled by unidirectional point-to-point links. Access to the transmission medium is controlled by a deterministic algorithm: a special bit pattern, called the token, circulates around the ring and gives the station holding the token momentary control of the transmission channel. Several service (transmission) disciplines have been proposed for token-ring networks. The most widely used service disciplines are the following [Ref. 86]:

- *Exhaustive service.* A station transmits packets until its buffers become empty. Only then it releases the token to its downstream neighbor.
- *Gated service.* A station transmits only the packets that are present in its buffers when it captures the token. Then it releases the token to the next station.
- *Limited services.* A station transmits packets until either its buffers become empty or a maximum number L of packets has been transmitted, whichever occurs first.
- *Ordinary service.* A station transmits packets up to one packet every time it captures the token. The ordinary service discipline is in fact a special case of the limited service with L = 1.
- *Timed-Token Service (TTS).* A token rotation timer (TRT) is used in each station to ensure the duration of each complete cycle of the token as it is seen by this particular station. The TRT is reset every time the token arrives at the station and immediately starts timing the duration of the new token rotation.

Compared with the IEEE 802.5 token-ring protocol, FDDI has two major differences in token handling:

- An FDDI station seizes a free token by absorption. On the contrary, an IEEE 802.5 station seizes a free token only by flipping a bit.
- In FDDI, a station issues a free token as soon as it completes the transmission of its frames, even if it has not yet begun to receive its own transmission. In IEEE 802.5, a station releases a free token only when it has received its own transmission.

Another difference is that FDDI defines two types of traffic: synchronous and asynchronous. For synchronous traffic, FDDI allocates a constant bandwidth for each station. But for asynchronous traffic, the access right to the network is regulated by the parameter TTRT (Target Token Rotation Time) and depends on the traffic.

2. Simulation model

The simulation model includes a LAN and its stations. The types of LAN considered are token-ring LANs with transmission speeds of 4, 16, and 100 Mbps. The service (transmission) discipline selected is the exhaustive service with 262,080 bits/frame and frame overhead of 200 bits/frame. It is assumed that the 100 Mbps FDDI follows the general token-ring protocols and the differences from IEEE 802.5 protocols are ignored because the stations in the model do not require synchronous transmission. The token passing time is set to zero because the delay to pass a token is relatively small compared to high volume still-image data.

In our simulation model, we assumed that the LAN has only one type of stations that generate high resolution graphics images to send to other stations. To emphasize the LAN utilization and delay characteristics, the processing time for

preparation, buffering, retrieval, and storage of images will not be included in the statistics collection. Each station generates high resolution image (CCIR A-601 format) file (about 5.6 Mbits/image) and the time between generation follows the exponential distribution with a mean of 60 seconds. We also assume that there is infinite size of buffer at the destination, thus we do not expect any delay in this way. The number of stations varies from 2 to 20 while other parameters stay the same. Figure 13 shows the components of the model.

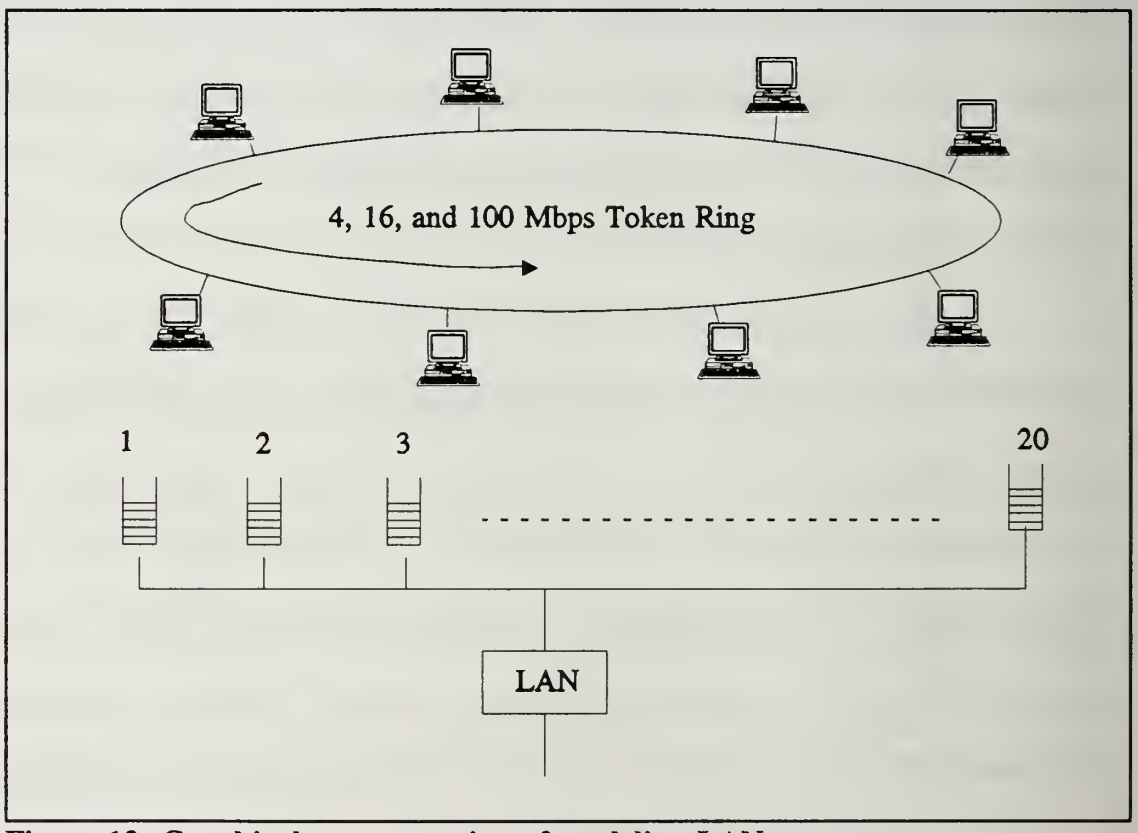


Figure 13. Graphical representation of modeling LAN

As for source of multimedia LAN traffic, we consider only one type of source -- still-image. There are several reasons for the use of only one type of traffic. First, the text file is very small compared to high volume multimedia data. Second,

the bi-level raster graphics are a subset of still-image and their size is also relatively small. Third, a CGM file can vary greatly in size and its transmission requirement varies according to coding methods (e.g., binary, character, and clean-text coding); but, in any way, its size is relatively small compared with a rasterized still-image file. Fourth, the full-motion video requires synchronous transmission of data. When compression technologies are introduced on full-motion video, there are complex bandwidth requirements. These requirements and complexity go beyond the scope of this study.

In conjunction with the fixed size image (5.6 Mbits/frame), the use of JPEG still-image compression chip is considered. As we described in Chapter III, the JPEG compression chip is available now and can achieve a compression ratio of 10:1 to 50:1 in one thirtieth of a second. The time for compression is not considered in this model. We assumed that the compression ratio of a JPEG chips follows a normal distribution. The distribution function is such that the output of the compression has a mean value of 336,000 bits/frame, lower bound of 112,000 bits/frame, and upper bound of 560,000 bits/frame. It is further assumed that the normal distribution has the standard deviation of 100,000 so that the compression the ratio moderately spread out between lower bound and upper bound.

C. MODEL TRANSLATION

The token ring access mechanism may be modeled by a single server representing the rotation of the free token. The model is translated into different simulation languages

-- SIMAN and LANNET II.5. The former is a general purpose simulation language and the latter is a special purpose LAN simulation tool. We now discuss each translation.

1. SIMAN

SIMAN is a general purpose simulation language developed by *Systems Modeling Corp.* for modeling discrete, continuous, and/or combined systems. SIMAN is designed around a logical modeling framework in which the simulation problem is segmented into a *model* component and an *experiment* component. The model describes the physical elements of the system (LAN, stations, image files, etc.) and their logical interrelationships. The experiment specifies the experimental conditions under which the model is to run, including elements such as initial conditions, resource availability, type of statistics collected, and length of a run.

The pseudo-code for the LAN model is;

```
CREATE arrivals (entity) as many as the number of stations
ASSIGN entity identification (attribute)
DELAY  exponentially with mean of 60 seconds
ASSIGN time stamp (attribute)
ROUTE  transfer the entity to a station
STATION at the entity's own station
QUEUE to await next token
SEIZE the channel
DELAY a quantum.
RELEASE the channel
TALLY the transmission delay
```

The variation of the above model is the case of a randomly varying file size. In that case, an entity is given a file size by normal distribution with the mean of 336000. Based on that file size, the transmission time without any delay is calculated

to collect delay time statistics. If the data is less than the data bits per frame, the transmission time is calculated based on LAN speed.

$$Transmissiontime = \frac{databits + frameoverhead}{LANspeed(Mbps)} \quad second$$

The source code for the model is shown in Appendix A.

2. LANNET II.5

The LANNET II.5 is a special purpose simulation package developed by *CACI Product* Company for simulation of LANs. It is a design tool which takes a user-specified LAN description and provides measures of utilization, conflicts, delays and response times.

In LANNET II.5, it is not necessary to program the model because it already contains the LAN parameters and characteristics. The graphical interface gives the user easy implementation of LAN simulation. The LANNET II.5 package consists of four parts;

- The LANGIN - Used to describe the LAN to be modeled.
- SIMLAN - The LAN simulation engine.
- LANPLOT - Used to plot/graph simulation statistics.
- LANAN - Post-processed LAN animation.

The LAN to be simulated is described using LANNET II.5 building blocks of LAN, STATION, GATEWAY, ROUTE, and SDF (Statistical Distribution Function). Each of these building blocks has a series of attributes whose values are supplied by the user. The LANGIN allows a user to build a LAN description using

LANNET II.5 building blocks. An example of LANGIN graphical user interface is shown in Figure 14.

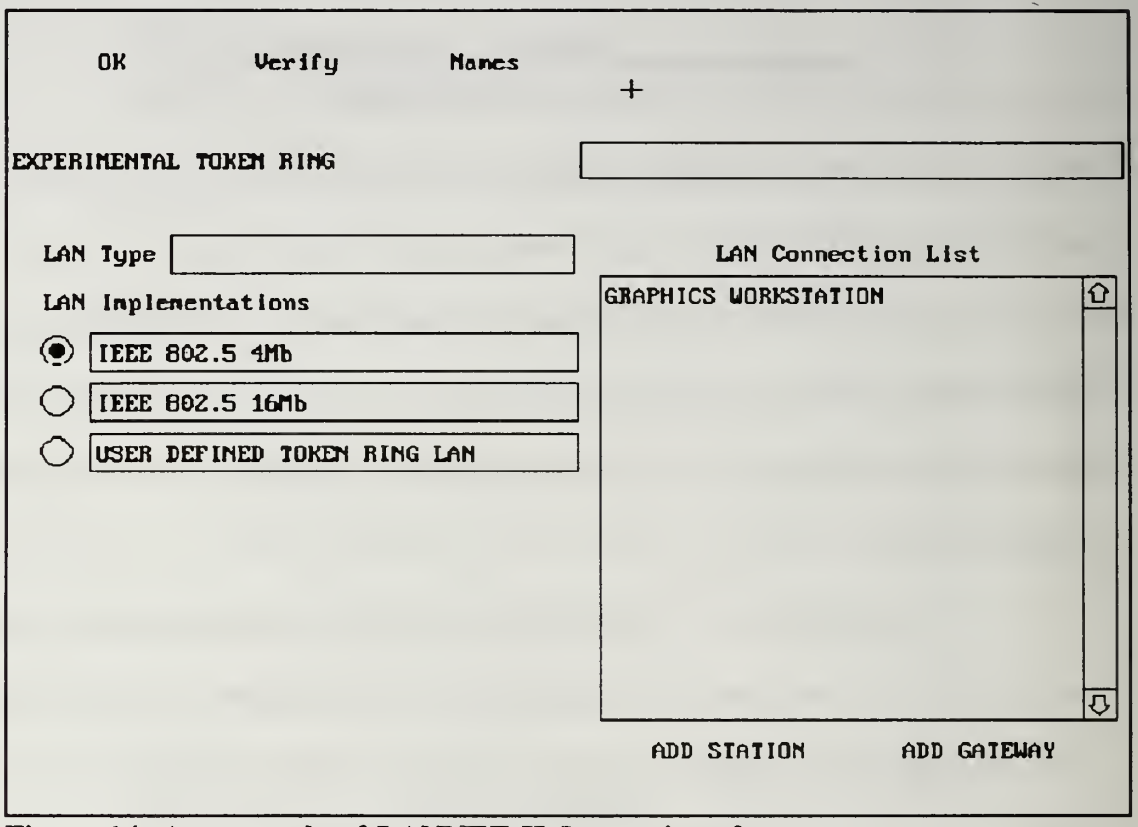


Figure 14. An example of LANNET II.5 user interface

D. EXPERIMENTS

The experiment part of a simulation study generates the information needed to fulfill the study's goal. To get enough information, a series of experiments are performed using both SIMAN and LANNET II.5. Even though LANNET II.5 provides very convenient ways of constructing and simulating the LANs, it lacks the flexibility of enabling customized and detailed modeling of LANs. It supports only one service discipline, exhaustive service, in token ring LANs. These are some of the reasons why a general simulation language is used for the model. The experiments include two parts:

the case of a fixed-size image file and the case of randomly varying image file size. In both cases, three LAN types -- IEEE 802.5 4 Mbps, IEEE 802.5 16 Mbps, and FDDI token ring LANs -- are considered. For each of these three LAN types, ten experiments are carried out by varying the number of stations from 2 to 20 by 2. Thus, sixty experiments are conducted in total. In SIMAN, each experiment has 10 replications without initialization to collect confidence interval for minimizing random variation.

The duration of the simulation is set to 4 hours to cover unstable initialization and real situations. The graphical analysis of simulation output indicates that LAN utilization stabilizes after 1 hour of simulation time, so the selection of the 4 hour length of simulation time appears reasonable.

V. SIMULATION RESULTS AND ANALYSIS

A. MODEL VERIFICATION

Verification is to determine that a simulation computer program performs as intended, i.e, debugging the computer model into a correctly working program [Ref. 90]. In this thesis, two verification methods are used to ensure the model works properly. First, built-in trace and animation functions of both LANNET II.5 and SIMAN are used for the purpose of finding logical errors. Second, to make sure that the internal parameters and logic of LANNET II.5 are correct, LANNET II.5 simulation results are compared with the results of the SIMAN model.

Both LANNET II.5 and SIMAN provide debugging tools, including interactive trace and animation. In the trace, the state of the simulated system (e.g., the contents of the event list, the state variables, statistical counters) is printed out on a file or screen just after each event occurs and compared with manual calculations to see if the program is operating as intended. The trace feature in LANNET II.5 provides the reports regarding activity, gateway, LAN, message, and station. The trace feature in SIMAN enables examining in detail the movement of entities through the system. It also gives a summary of the action taken at each block through which an entity has passed.

In addition to the trace feature, animation is an effective way of validating the model. An animation can immediately expose most logical errors. LANNET II.5 provides a LAN animation tool which provides graphical LAN animation using

simulation results from SIMLAN. This tool makes it possible to actually see the modeled LAN in operation, and trace messages describing simulation activity may be displayed concurrently with the animation. The location and color of each construct is automatically created from the LAN description. SIMAN has animation tools named CINEMA. They provide a graphical interface that helps users in drawing layouts of the modeled system and linking the model and graphical objects.

Using both trace and animation features, any logical error is identified and corrected. After the logic verification process, the results from both LANNET II.5 and SIMAN are compared. The comparison confirms that the model is correct.

B. SIMULATION RESULTS AND DISCUSSION

Two different properties of LAN performance are observed. The utilization is calculated as percentage of time a LAN is busy during the simulation run. The time required for an image file to move from a source station to a destination station in a LAN is defined as the total transfer time in this model.

The delay time is the difference between the transfer time and the transmission time which is calculated by dividing the size of the image file by the LAN transmission speed. A ring network provides a single shared path for all data. Hence, as traffic increases from the attached stations, transfer delay increases. The transfer delay is the most relevant for asynchronous traffic.

Figure 15 through Figure 18 show the simulation results of the mean LAN utilization and delay with the varying number of stations ranging from 2 to 20.

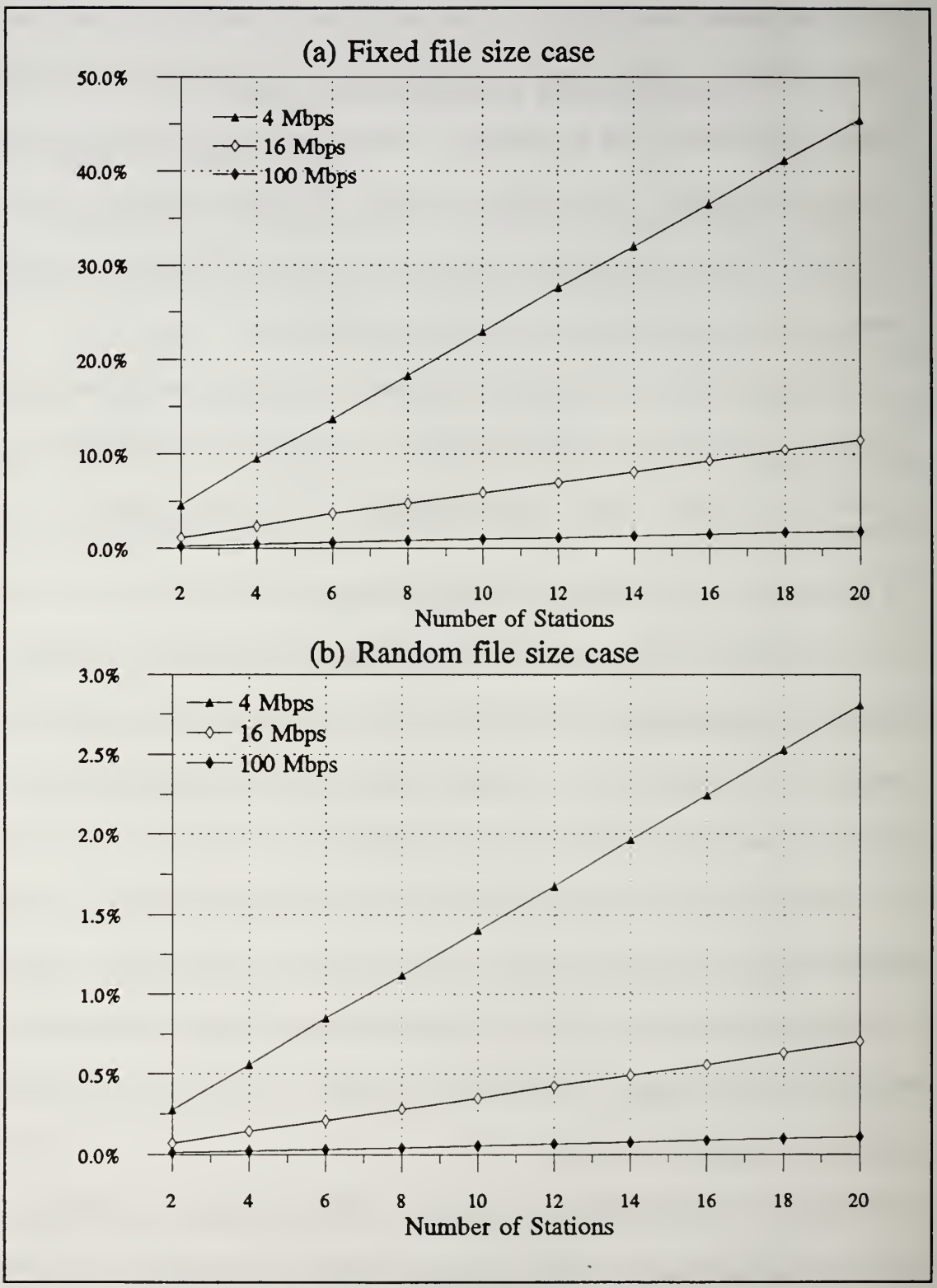
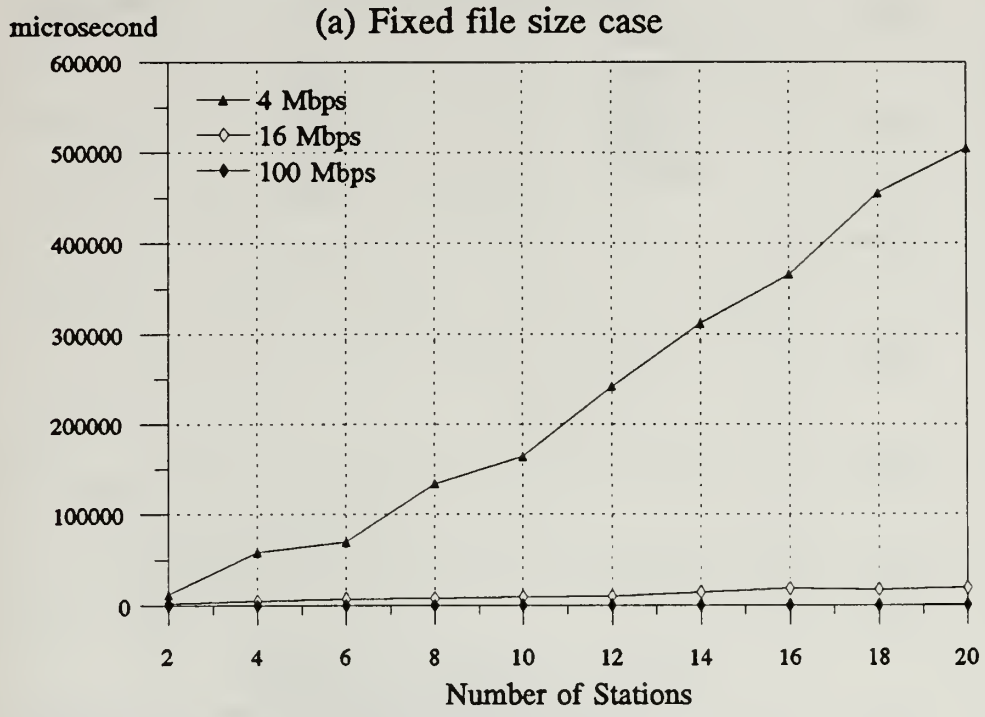


Figure 15. Utilization results from LANNET II.5



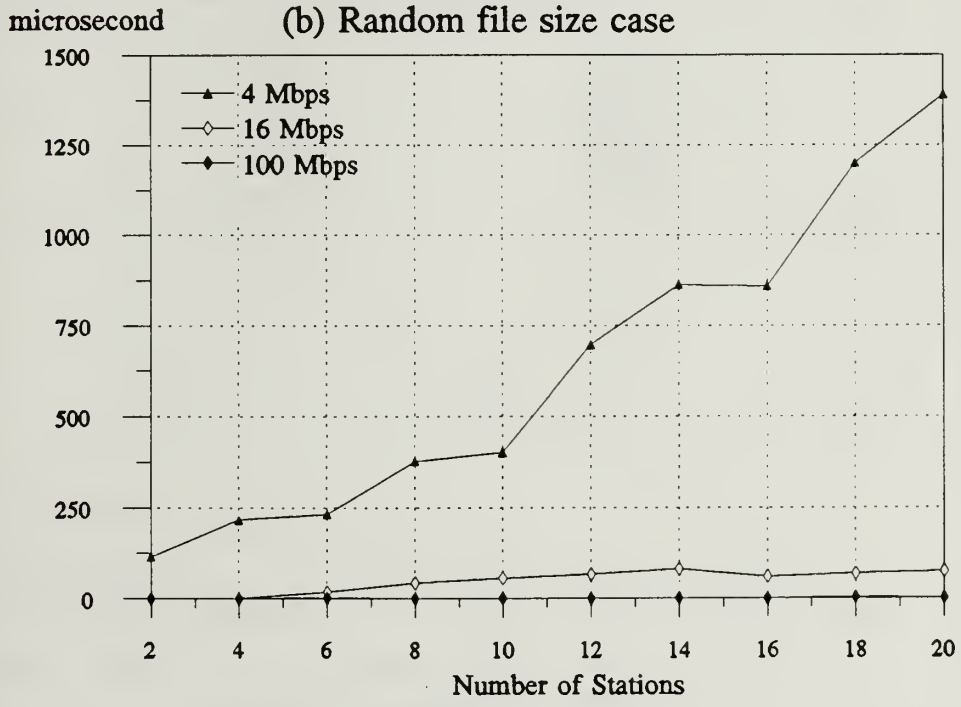


Figure 16. Average delay results from LANNET II.5

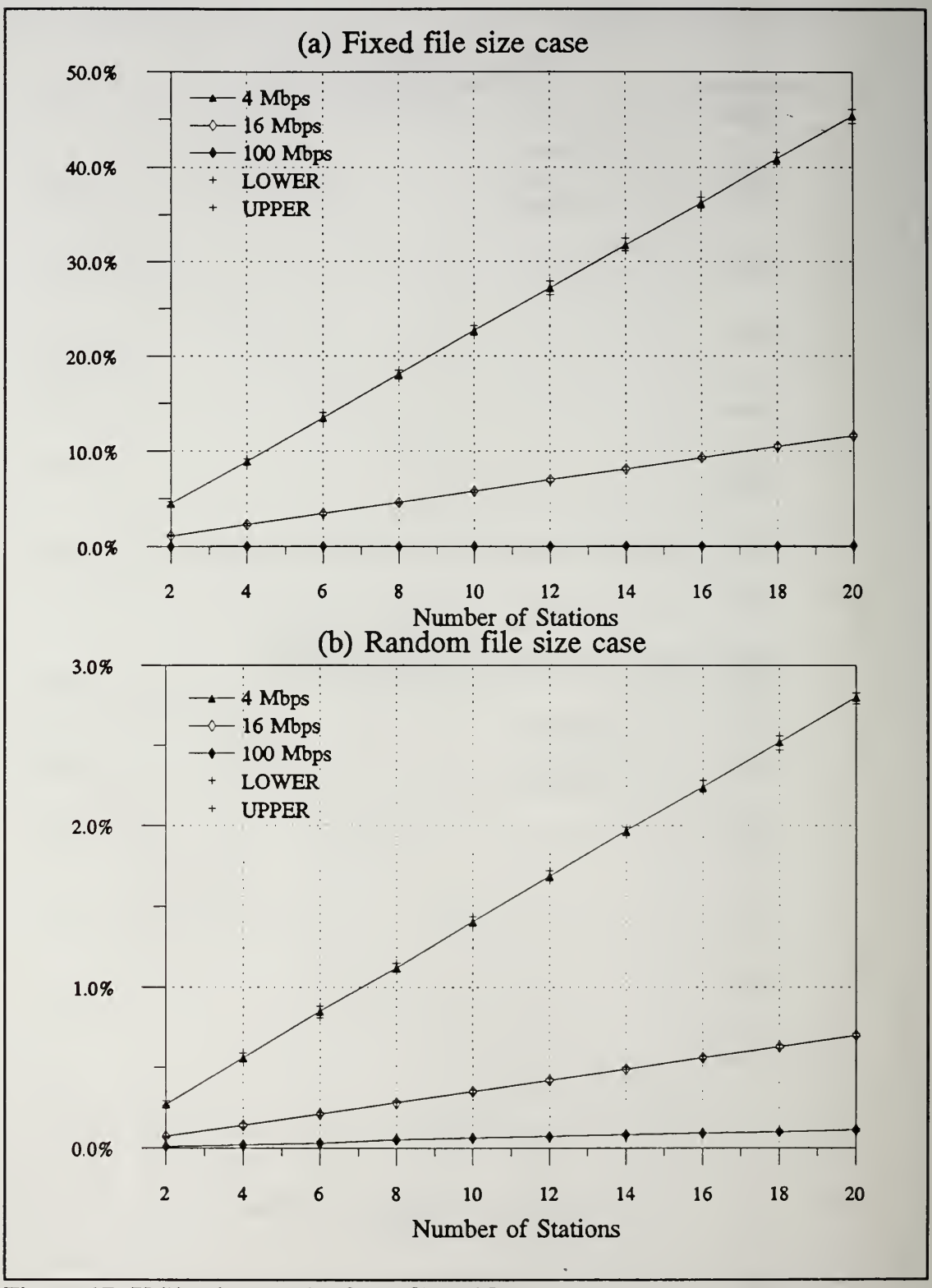


Figure 17. Utilization results from SIMAN

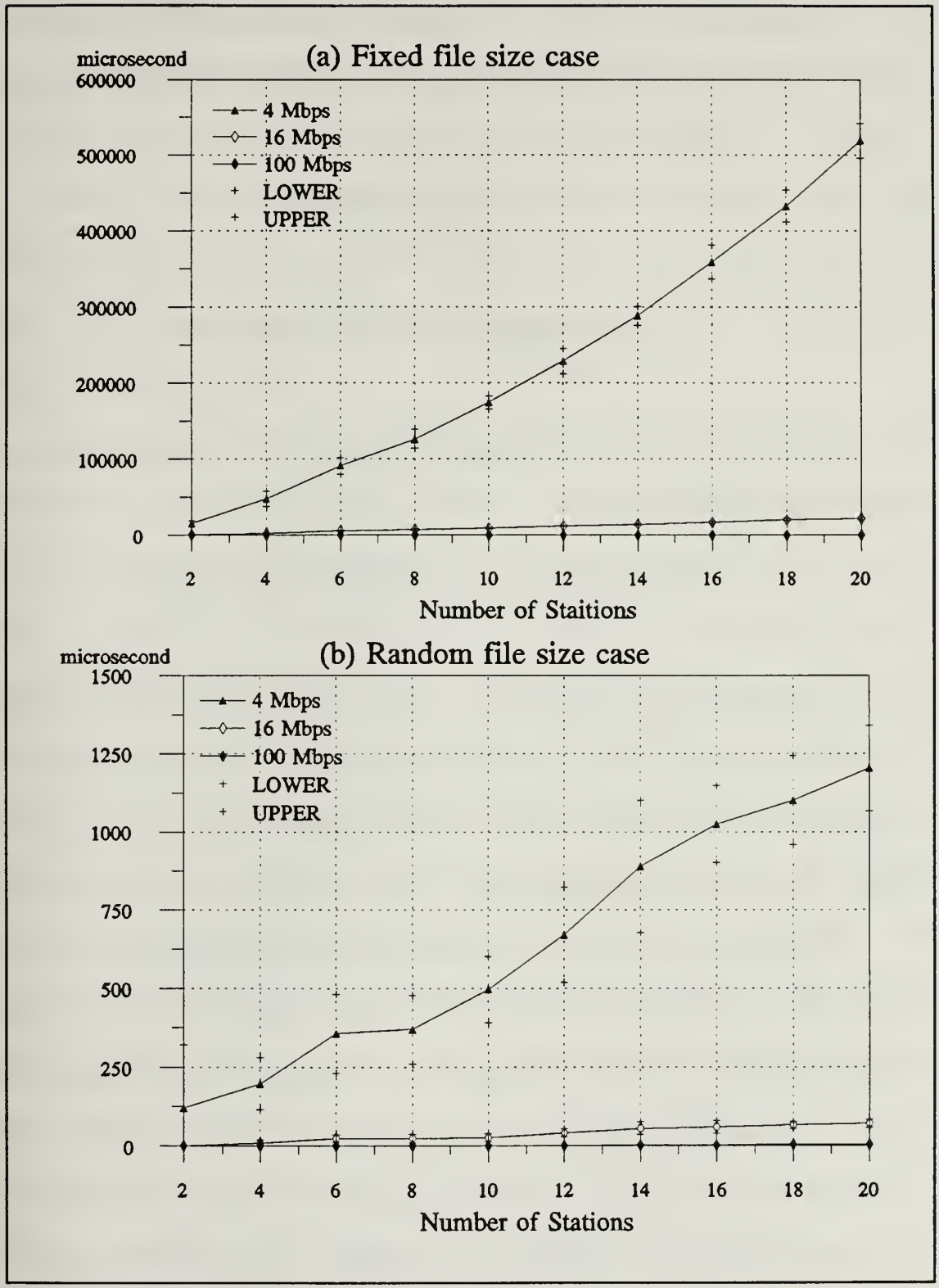


Figure 18. Average delay results from SIMAN

The confidence interval is an indication of the reliability of the estimator of the mean. With 10 experiments for each case, 95% confidence intervals are calculated as follows:

$$\mu = [\bar{x}-h, \bar{x}+h]$$

where

$\bar{x}$: *point estimator of the mean(sample mean)*
$h = t_{9,\ 0.05/2}\ s(\bar{x})$

The sample mean, $\bar{x}$, and the sample variance, s^2, of x and $\bar{x}$ from the 10 observations are as follows:

$$\bar{x} = \sum_i \frac{x_i}{10}, \quad s^2(x) = \sum_i \frac{(x_i-\bar{x})^2}{9}, \quad s^2(\bar{x}) = \frac{s^2(x)}{10}$$

As we see in Figure 17 and Figure 18, the wide interval is resulted from the large underlying variability of the exponential distribution for the arrival process. It is reasonable that the confidence interval for the average delay of randomly varying file size case is wider than the fixed file size case, because the former has more random factors.

In the fixed file size case, the utilization grows linearly with the increasing number of stations. The utilization for 4 Mbps LAN is approximately 45% when the number of stations reaches 20. The 45% utilization rate is very high, possibly causing a major network bottleneck. In the case of variable file size, where it is assumed the JPEG compression chip is utilized, the utilization goes down to about 3 % when the number of stations reaches 20. Comparing two situation, i.e., 45% utilization in non-compression situation and 3% utilization in compression situation with number of

stations 20, it justifies the adoption of compression chip which compresses image files with a 10 to 50 compression ratio. Considering other LAN traffics (e.g, file retrieving, messages, etc.), the use of compression chip is highly recommended.

Since the maximum delay measure can be changed by simulation length, the maximum delay results are not presented. But with the given simulation length of 4 hours, the maximum delay ranges from 1.28 second at 2 stations to 6.2 seconds at 20 stations in 4 Mbps token ring.

In the 16 Mbps token ring LAN case, the performance is acceptable in both utilization and average delay at given LAN load. Utilization of 12% and an average delay of 300 microseconds at maximum load is reasonably acceptable in image browsing activity. Therefore, it is concluded that the 16 Mbps LAN can provide acceptable performance under certain situations (e.g., no other traffics, maximum of 20 stations, mean job request interval of 60 seconds, and job size of 5.6 Mbits). From another point of view, if we consider the multimedia network in which synchronous data (e.g., packetized voice and video) and asynchronous data are transmitted, the 16 Mbps bandwidth and token-passing protocol may not satisfy the requirements. The requirements of synchronous data are guaranteed bandwidth and delay. Current collision and token- passing type LAN protocols cannot support guaranteed delay for synchronous data. Currently, another LAN protocol is being developed by IEEE. The IEEE 802.9 LAN standard is standard for Integrated Voice and Data (IVD) LANs. The specification defines two channels: a packet channel for data applications, and a circuit channel for voice and digital video.

The FDDI token ring is the most promising candidate for the multimedia LAN. With dramatically increased bandwidth, FDDI meets the requirements for both traditional LAN applications and multimedia applications. The timed-token protocol of FDDI provides guaranteed delay for synchronous data transmission even at high network load, through it cannot guarantee response time smaller than the round trip delay.

To better support high-volume synchronous traffic, Mark and Lee [Ref. 85] proposed a dual-ring LAN which supports real-time synchronous voice and video services, and multilevel priority asynchronous data traffic types using a packet-switching operation. FDDI-II has also been proposed. Martini and Thomas [Ref. 89] proposed FDDI-II which includes circuit switching capability in addition to the packet switching capability of basic FDDI.

VI. CONCLUSION

Multimedia e-mail will be the next step of developments in exchanging information among remote users of the computer network. All the society stands to benefit from the successful implementation of multimedia e-mail. The two barriers hindering the wide use of multimedia e-mail are its enormous bandwidth requirements and the lack of standards for exchange format. The bandwidth restrictions are being resolved by advanced computing and the deployment of ISDN, B-ISDN, and other high-speed telecommunication networks. The other barrier, the lack of standards, is also being resolved by international standards organizations' effort. The representative two organizations, ISO and CCITT, are devoted to the standardization of multimedia e-mail, alone or jointly. The resulting standards are X.400 and ODA. X.400 was standardized in 1984 and revised in 1988; ODA was standardized in 1988 and is currently being revised to allow more components. ODA supports formatted text, raster graphics, and geometric graphics. The future standards will be able to support high bandwidth uses such as high-resolution color still-image, full-motion video, voice, audio, and animation.

For each component, there also have been individual and joint standardization efforts. Currently, CGM, JPEG, and MPEG standards are being developed or revised for geometric graphics, still-images, and full-motion videos, respectively. The addition of these components will increase bandwidth requirements. The simulation study shows that the high-resolution image browsing activity in a Local Area Network

(LAN) will burden the low-speed LANs. The adoption of compression chips or high-speed LANs such as FDDI will make such high bandwidth activities feasible. In the case of full-motion video, the synchronous transmission needs requires the development of new protocols.

The combination of the wide bandwidth, compression technologies of source data, and new protocol will facilitate the deployments of true multimedia e-mail and related multimedia applications, and the results will enhance productivity of the future society.

APPENDIX A. SIMAN LAN MODEL AND EXPERIMENTAL SOURCE CODE

1. MODEL

```
BEGIN, Y, SIMLAN;
;
          CREATE, No_of_Stations: 0, 1;
;
          ASSIGN: X(1) = X(1) + 1;
          ASSIGN: Station_ID = X(1);
;
GOON      DELAY: EXPO(60);
          ASSIGN: TimeIn = TNOW + Transfer_Time;
          ROUTE: 0, Station_ID;
;
          STATION, 1;
Q1        QUEUE, 1:DETACH;
          STATION, 2;
Q2        QUEUE, 2:DETACH;
          STATION, 3;
Q3        QUEUE, 3:DETACH;
          STATION, 4;
Q4        QUEUE, 4:DETACH;
          STATION, 5;
Q5        QUEUE, 5:DETACH;
          STATION, 6;
Q6        QUEUE, 6:DETACH;
          STATION, 7;
Q7        QUEUE, 7:DETACH;
          STATION, 8;
Q8        QUEUE, 8:DETACH;
          STATION, 9;
Q9        QUEUE, 9:DETACH;
          STATION, 10;
Q10       QUEUE, 10:DETACH;
          STATION, 11;
Q11       QUEUE, 11:DETACH;
          STATION, 12;
Q12       QUEUE, 12:DETACH;
          STATION, 13;
Q13       QUEUE, 13:DETACH;
```

```
            STATION, 14;
Q14         QUEUE, 14:DETACH;
            STATION, 15;
Q15         QUEUE, 15:DETACH;
            STATION, 16;
Q16         QUEUE, 16:DETACH;
            STATION, 17;
Q17         QUEUE, 17:DETACH;
            STATION, 18;
Q18         QUEUE, 18:DETACH;
            STATION, 19;
Q19         QUEUE, 19:DETACH;
            STATION, 20;
Q20         QUEUE, 20:DETACH;
            QPICK, CYC:
                Q1: Q2: Q3: Q4: Q5: Q6: Q7: Q8: Q9: Q10:
                Q11: Q12: Q13: Q14: Q15: Q16: Q17: Q18: Q19: Q20;
            SEIZE: Channel;
            DELAY: Transfer_Time;
            RELEASE: Channel;
            TALLY: Transmission Delay, INT(TimeIn): NEXT(GOON);
END;
```

2. EXPERIMENTAL

```
BEGIN;
PROJECT, SIMLAN, NAGJUNG CHOI;
ATTRIBUTES:     TimeIn:
                Station_ID;
VARIABLES:      No_of_Stations, 2:
                Transfer_Time, 1.4011;
QUEUES:         20;
STATIONS:       20;
RESOURCES:Channel,1;
;
DSTAT:NR(Channel), Channel utilization;
TALLIES: Transmission Delay;
OUTPUTS:    DAVG(Channel Utilization), "util1-02.dat":
            TAVG(Transmission Delay), "dly1-02.dat";
; Simulation time is set to 2 hours (7200 seconds) and 10 replications
; without initialization
REPLICATE, 10, 0, 7200, N;
END;
```

APPENDIX B. SIMULATION RESULTS

1. Fixed file size case

Number of Stations	Utilization			Average delay (microsecond)		
	4 Mbps	16 Mbps	100 Mbps	4 Mbps	16 Mbps	100 Mbps
2	4.50%	1.15%	0.02%	15400	1076	0
4	8.92%	2.28%	0.02%	47720	2813	0
6	13.50%	3.49%	0.03%	91170	5606	1.375
8	18.10%	4.61%	0.06%	126000	7355	0.918
10	22.70%	5.79%	0.05%	174000	9149	0.651
12	27.20%	6.97%	0.06%	289000	11860	1.503
14	31.80%	8.13%	0.07%	289000	14470	0.5268
16	36.20%	9.30%	0.08%	359000	16790	0.5095
18	40.90%	10.50%	0.09%	433000	20050	1.91
20	45.40%	11.60%	0.10%	519000	21650	1.996

2. Random file size case (compression is applied)

Number of Stations	Utilization			Average delay (microsecond)		
	4 Mbps	16 Mbps	100 Mbps	4 Mbps	16 Mbp	100 Mbps
2	0.27%	0.07%	0.01%	121	0	0
4	0.56%	0.14%	0.02%	197.9	9.295	0
6	0.85%	0.21%	0.03%	355.8	24.68	0.5373
8	1.12%	0.28%	0.06%	368.8	24.54	0.6168
10	1.41%	0.35%	0.06%	496.3	26.19	1.367
12	1.69%	0.42%	0.07%	671.3	41.15	1.474
14	1.97%	0.49%	0.08%	889.8	56.21	1.661
16	2.24%	0.56%	0.09%	1025	59.7	2.078
18	2.52%	0.63%	0.10%	1101	65.91	2.631
20	2.80%	0.70%	0.11%	1205	71.13	2.514

APPENDIX C. GLOSSARY

ABAC	Adaptive Binary Arithmetic Coder
ADCT	Adaptive Discrete Cosine Transform
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
ASN.1	Abstract Syntax Notation One
AU	Access Unit
BCTF	Block Cosine Transform with Filtering
BLT	Block List Transform
BSPC	Block Separated Component Progressive Coding
CALS	Computer-Aided Acquisition and Logistics Support
CCIR	International Radio Consultative Committee
CCITT	International Telegraph and Telephone Consultative Committee
CD-I	Compact Disc-Interactive
CD-ROM	Compact Disc Read Only Memory
CGM	Computer Graphics Metafile
CIE	Commission Internationale L'Eclairage
CMTT	Committee on Mix of Telephone and Television
CPU	Central Processing Unit
CVQ	Component Vector Quantization

CYMK	Cyan/Yellow/Magenta/Black
DARPA	Defence Advanced Research Projects Agency
DCTD	Adaptive DCT and Differential Entropy Coding
DCTV	Discrete Cosine Transform with Vector Quantization
DFT	Discrete Fourier Transform
DIS	Draft International Standard
DoD	Department of Defence
DP	Draft Proposal
DVI	Digital Video Interface
FDCT	Forward Discrete Cosine Transform
FDDI	Fiber Distributed Data Interface
FIPS	Federal Information Processing Standard
FTAM	File Transfer, Access and Management
GBTC	Generalized Block Truncation Coding
GKS	Graphics Kernel Systems
GOSIP	Government Open System Interconnection Protocol
HDTV	High Definition TeleVision
IDCT	Inverse Discrete Cosine Transform
IEEE	Institute of Electrical and Electronic Engineers
IGES	Initial Graphic Exchange Specification
IPM	InterPersonal Messaging
IS	International Standard

ISDN	Integrated Service Digital Network
ISO	International Organization for Standardization
ITU	International Telecommunications Union
IVD	Integrated Voice and Data
JPEG	Joint Photographic Experts Group
LAN	Local Area Network
MHS	Message Handling System
MPEG	Moving Picture Experts Group
MS	Message store
MTA	Message Transfer Agent
MTS	Message Transfer System
NTSC	National Television Systems Committee
ODA	Office Document Architecture
ODIF	Office Document Interchange Format
ODL	Office Document Language
PCS	Progressive Coding Scheme
PHIGS	Programmers' Hierarchical Interactive Graphics System
PRBN	Progressive Recursive Binary Arithmetic
RGB	Red/Green/Blue
SGML	Standard Generalized Markup Language
TC	Technical Committee
TIFF	Tagged Image File Format

TRT	Token Rotation Timer
TTS	Timed-Token Service
UA	User Agent
VDM	Virtual Device Metafile
VT	Virtual Terminal
WD	Working Draft
WG	Working Group

APPENDIX D. LIST OF STANDARDS

1. Standards for compound document format

a. International standards

ODA ISO 8613-1, Information Processing Systems - Text and Office Systems - Office Document Architecture (ODA) and Interchange Format - Part 1: Introduction and General Principles (1988)

ISO 8613-2, Information Processing Systems - Text and Office Systems - Office Document Architecture (ODA) and Interchange Format - Part 2: Document Structure

ISO 8613-4, Information Processing Systems - Text and Office Systems - Office Document Architecture (ODA) and Interchange Format - Part 4: Document Profile

ISO 8613-5, Information Processing Systems - Text and Office Systems - Office Document Architecture (ODA) and Interchange Format - Part 5: Office Document Interchange Format (ODIF)

ISO 8613-6, Information Processing Systems - Text and Office Systems - Office Document Architecture (ODA) and Interchange Format - Part 6: Character Content Architectures

ISO 8613-7, Information Processing Systems - Text and Office Systems - Office Document Architecture (ODA) and Interchange Format - Part 7: Raster Graphics Content Architectures

ISO 8613-8, Information Processing Systems - Text and Office Systems - Office Document Architecture (ODA) and Interchange Format - Part 8: Geometric Graphics Content Architectures

CCITT Recommendation T.410 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Overview

CCITT Recommendation T.411 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Introduction and General Principles

CCITT Recommendation T.412 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Document Structure

CCITT Recommendation T.414 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Document Profile

CCITT Recommendation T.415 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Document Interchange Format (ODIF)

CCITT Recommendation T.416 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Character Content Architectures.

CCITT Recommendation T.417 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Raster Graphics Content Architectures.

CCITT Recommendation T.418 (Blue Book, 1988) Open Document Architecture (ODA) and Interchange Format - Geometric Graphics Content Architectures.

SGML ISO 8879, Information Processing - Text and Office Systems - Standard Generalized Markup Language (1986)

DSSSL ISO/IEC/ JTC 1/SC 18, Document Style Semantics and Specification Language (Currently Draft form)

b. Industry standards

MO:DCA Mixed Object: Document Content Architecture (IBM)

RTF Rich Text Format (Microsoft)

CDA Compound Document Architecture (DEC)

DDIF Digital Document Interchange Format (DEC)

EPS Encapsulated PostScript

PCL Printer Control Language (Hewlett-Packard)

2. Character

ISO 9541 Information Processing - Font and Character Information Interchange

ISO 2022 Information Processing - ISO 7-bit and 8-bit Coded Character Sets - Code Extension Techniques (1986)

ISO 6429 Information Processing - ISO 7-bit and 8-bit Coded Character Sets - Additional Control Functions for Character Imaging Devices (1983)

ISO 6937 Information Processing - Coded Character Sets for Text Communication (1983)

ASCII American Standard Code for Information Interchange

3. Raster graphics

CCITT Recommendation T.6, Facsimile Coding Schemes and Coding Control Functions for Group 4 Facsimile Apparatus (1984)

4. Geometric graphics

CGM ISO 8632, Information Processing System - Computer Graphics - Metafile for the Storage and Transfer of Picture Description Information (1987; Amendment 1, 1990; Amendment 3, 1991)

GKS ISO 7942, Information processing system - Computer Graphics - Functional Specification of the Graphical Kernel System (GKS, 1985)

PHIGS ISO 9592, Information Processing Systems - Computer Graphics - Programmer's Hierarchical Interactive Graphics System (PHIGS, 1988)

IGES Initial Graphic Exchange Specification

5. Digital video

a. International standards

JPEG ISO 10918, JPEG Digital Compression and Coding of Continuous-Tone Still Images (Draft Standard, 1991)

MPEG ISO 11172, Coding of Moving Pictures and Associated Audio (MPEG, Committee Draft, 1990)

H.261 CCITT Recommendation H.261, Video Codec for Audio Visual Services at px64 kbits/s (1990)

b. Industry Standards

DVI Digital Video Interactive

CD-I Compact Disc-Interactive

6. Message Handling Systems (MHS)

MHS CCITT Recommendation X.400, (Blue Book, 1988), Message Handling Systems: System Model-Service Elements.

CCITT Recommendation X.401, (Blue Book, 1988), Message Handling Systems: Basic Service Elements and Optional User Facilities.

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CCITT Recommendation X.411, (Blue Book, 1988), Message Handling Systems: Message Transfer Layer.

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